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Omaha District

2010 Report

Water Quality Conditions at Tributary Projects in the Omaha District




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Water Quality Conditions at Tributary Projects in the Omaha District

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1 INTRODUCTION

1.1 OMAHA DISTRICT WATER QUALITY MANAGEMENT PROGRAM

The Omaha District (District) of the U.S. Army Corps of Engineers (Corps) is implementing a Water Quality Management Program (WQMP) as part of the operation and maintenance activities associated with managing the Corps' civil works projects in the District. The WQMP addresses surface water quality management issues and adheres to the guidance and requirements specified in the Corps' Engineering Regulation – ER 1110-2-8154, "Water Quality and Environmental Management for Corps Civil Works Projects" (USACE, 1995). The following four goals have been established for the District's WQMP (USACE, 2009):

1) Ensure that surface water quality, as affected by District Projects and their regulation, is suitable for project purposes, existing water uses, and public health and safety; and is in compliance with applicable Federal, Tribal, and State water quality standards.
2) Establish and maintain a surface water quality monitoring and data evaluation program that facilitates the achievement of water quality management objectives, allows for the characterization of water quality conditions, and defines the influence of District Projects on surface water quality.
3) Establish and maintain strong working partnerships and collaboration with appropriate entities within and outside the Corps regarding surface water quality management at District Projects.
4) Document the water quality management activities of the District's Water Quality Management Program and surface water quality conditions at District Projects to record trends, identify problems and accomplishments, and provide guidance to program and project managers.

Water quality data collection and assessment are of paramount importance to the implementation of the District's WQMP.

The District prepares periodic reports to regularly assess and document surface water quality conditions present at Corps civil works tributary projects in the District. These reports describe existing surface water quality conditions, identify surface water quality trends, and identify any evident surface water quality management issues. The periodic reporting of surface water quality conditions provides information to facilitate water quality management decisions regarding the operation and regulation of the Corps Tributary Projects.

1.2 CORPS CIVIL WORKS TRIBUTARY PROJECTS WITHIN THE OMAHA DISTRICT

The locations of Corps tributary civil works project areas within the District are shown on Figure 1.1. Table 1.1 provides background information on the projects. These are the Tributary Projects under the purview of the District's WQMP.

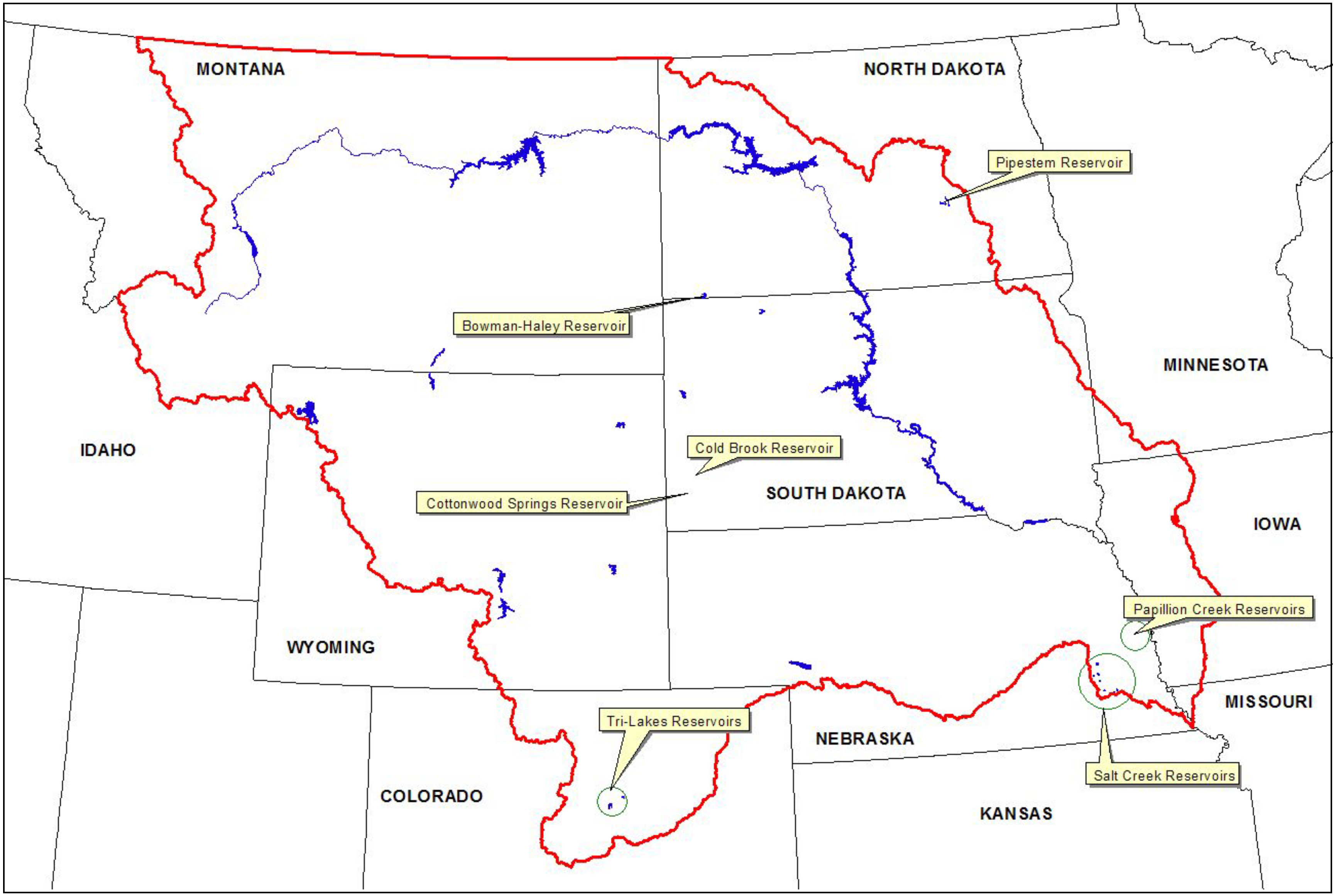

Figure 1.1. Tributary Projects in the Omaha District. (Refer to Table 1.1 for project background information.)

Table 1.1. Background information for the Tributary Projects located in the Omaha District.

Project	Location	Dam Closure	Reservoir Size [1]	Authorized Proposes[2]	Water Quality Designated Beneficial Uses[3]
Tri-Lakes Reservoirs (Colorado):					
Bear Creek	Denver, CO	1977	107 A (mp)	FC, Rec, FW	Rec, CAL, DWS, AWS
Chatfield	Denver, CO	1973	1,423 A (mp)	FC, Rec, FW, WS	Rec, CAL, DWS, AWS
Cherry Creek	Denver, CO	1948	844 A (mp)	FC, Rec, FW	Rec, WAL, DWS, AWS
Salt Creek Reservoirs (Nebraska):					
Bluestem (Dam #4)	Lincoln, NE	1962	309 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Branched Oak (Dam #18)	Lincoln, NE	1967	1,847 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Conestoga (Dam #12)	Lincoln, NE	1963	217 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Holmes (Dam #17)	Lincoln, NE	1962	123 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Olive Creek (Dam #2)	Lincoln, NE	1963	162 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Pawnee (Dam #14)	Lincoln, NE	1964	739 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Stagecoach (Dam #9)	Lincoln, NE	1963	195 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Twin Lakes (East and West) (Dam #13)	Lincoln, NE	1965	236 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Wagon Train (Dam #8)	Lincoln, NE	1962	277 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Yankee Hill (Dam #10)	Lincoln, NE	1965	211 A (mp)	FC, Rec, FW	Rec, WAL, AWS, Aes
Papillion Creek Reservoirs (Nebraska):					
Ed Zorinsky (Dam #18)	Omaha, NE	1984	259 A (mp)	FC, Rec, FW, WQ	Rec, WAL, AWS, Aes
Glenn Cunningham (Dam #11)	Omaha, NE	1974	377 A (mp)	FC, Rec, FW, WQ	Rec, WAL, AWS, Aes
Standing Bear (Dam #16)	Omaha, NE	1972	125 A (mp)	FC, Rec, FW, WQ	Rec, WAL, AWS, Aes
Wehrspann (Dam #20)	Omaha, NE	1982	239 A (mp)	FC, Rec, FW, WQ	Rec, WAL, AWS, Aes
North Dakota Reservoirs:					
Bowman-Haley	Bowman, ND	1966	1,732 A (mp)	FC, Rec, FW, WQ, WS	Rec, WAL, FW, AWS
Pipestem	Jamestown, ND	1973	840 A (mp)	FC, Rec, FW, WQ	Rec, WAL, AWS, Aes
South Dakota Reservoirs:					
Cold Brook	Hot Springs, SD	1952	36 A (mp)	FC, Rec, FW, WQ	Rec, FW, CAL, AWS, DWS
Cottonwood Springs	Hot Springs, SD	1969	41 A (mp)	FC, Rec, FW, WQ	Rec, FW, WAL, AWS, DWS

(1) A = acres and mp = top of multipurpose pool.
(2) Purposes authorized under Federal laws for the operation of the Corps projects.
FC = Flood Control, Rec = Recreation, FW = Fish & Wildlife, WS = Water Supply, WQ = Water Quality.
(3) Water quality dependent beneficial uses designated to the reservoir in State water quality standards pursuant to the Federal Clean Water Act.
Rec = Recreation, CAL = Coldwater Aquatic Life, DWS = Domestic Water Supply, AWS = Agricultural Water Supply, WAL = Warmwater Aquatic Life, Aes = Aesthetics, and FW = Fish and Wildlife.

1.3 WATER QUALITY MONITORING PURPOSES AND OBJECTIVES

The District has established 4 purposes and 12 monitoring objectives for surface water quality monitoring under its WQMP. These monitoring purposes and objectives were established to meet the water quality information needs of the WQMP and the water quality management objectives, data collection rules and objectives, data application guidance, and reporting requirements identified in ER 1110-2-8154. The monitoring purposes and objectives that have been established are:

Purpose 1: Determine surface water quality conditions at District Projects.

Monitoring Objectives:

1) For new District water resource projects establish baseline surface water quality conditions as soon as possible and appropriate.
2) Characterize the spatial and temporal distribution of surface water quality conditions at District Projects.
3) Identify pollutants and their sources that are affecting surface water quality and the aquatic environment at District Projects.
4) Evaluate water/sediment interactions and their effects on overall surface water quality at District Projects.
5) Identify the presence and concentrations of contaminants in indicator and human-consumed fish species at District Projects.

6) Investigate unique events (e.g., fish kills, hazardous waste spills, operational emergencies, health emergencies, public complaints, etc.) at District Projects that may have degraded surface water quality or impacted the aquatic environment.

Purpose 2: Document surface water concerns that are due to the operation and reservoir regulation of District Projects.

Monitoring Objectives:

7) Determine if surface water quality conditions at District Projects or attributable to District operations or reservoir regulation (i.e., downstream conditions resulting from reservoir discharges) meets applicable Federal, Tribal, and State water quality standards.
8) Determine if surface water quality conditions at District Projects or attributable to District operations or reservoir regulation are improving, degrading, or staying the same over time.
9) Apply water quality models to assess surface water quality conditions at District Projects.

Purpose 3: Provide data to support project operations and reservoir regulation for effective management and enhancement of surface water quality and the aquatic environment.

Monitoring Objectives:

10) Provide surface water quality data required for real-time regulation of District Projects.
11) Collect the information needed to design, engineer, and implement measures or modifications at District Projects to enhance surface water quality and the aquatic environment.

Purpose 4: Evaluate the effectiveness of structural or regulation measures implemented at District Projects to enhance surface water quality and the aquatic environment.

Monitoring Objective:

12) Evaluate the effectiveness of implemented measures at District Projects to improve surface water quality and the aquatic environment.

1.4 DATA COLLECTION APPROACHES

The District has identified four approaches to surface water quality data collection (USACE, 2009). These four surface water quality data collection approaches are:

- Long-term fixed-station ambient monitoring,
- Intensive surveys,
- Special studies, and
- Investigative monitoring.

Long-term fixed-station ambient monitoring is intended to provide information that will allow the District to determine the status and trends of surface water quality at District Projects. This type of sampling consists of systematically collecting samples at the same location over a long period of time (e.g., collecting monthly water samples at the same site for several years).

Intensive surveys are intended to provide more detailed information regarding surface water quality conditions at District Projects. They typically will include more sites sampled over a shorter timeframe than long-term fixed-station monitoring. Intensive surveys will provide the detailed water quality information needed to thoroughly understand surface water quality conditions at a project.

Special studies are conducted to address specific information needs. Special studies may be undertaken to collect the information needed to "scope-out" a specific surface water quality problem, apply water quality models, design and engineer modifications at projects, or evaluate the effectiveness of implemented surface water quality management measures.

Investigative monitoring is typically initiated in response to an immediate need for surface water quality information at a District Project. This may be in response to an operational situation, the occurrence of a significant pollution event, public complaint, or a report of a fish kill. Any District response to a pollution event or fish kill would need to be coordinated with the appropriate Tribal, State, and Local agencies. The type of sampling that is done for investigative purposes is highly specific to the situation under investigation.

1.5 GENERAL SURFACE WATER QUALITY CONCERNS IN THE OMAHA DISTRICT

The District was identified six general concerns that are impacting surface water quality at Corps projects to some extent. These six general surface water quality concerns are: 1) reservoir eutrophication and hypolimnetic dissolved oxygen depletion, 2) sedimentation, 3) shoreline erosion, 4) bioaccumulation of contaminants in aquatic organisms, 5) occurrence of pesticides, and 6) urbanization.

1.5.1 RESERVOIR EUTROPHICATION AND HYPOLIMNETIC DISSOLVED OXYGEN DEPLETION

Reservoirs are commonly classified or grouped by trophic or nutrient status. The natural progression of reservoirs through time is from an oligotrophic (i.e., low nutrient/low productivity) through a mesotrophic (i.e., intermediate nutrient/intermediate productivity) to a eutrophic (i.e., high nutrient/high productivity) condition. The tendency toward the eutrophic or nutrient-rich status is common to all impounded waters. The eutrophication, or enrichment process, can be accelerated by nutrient additions to the reservoir resulting from cultural activities.

As deeper, temperate lakes warm in the spring and summer they typically become thermally stratified, due to the density differences of the water, into three vertical zones: 1) epilimnion, 2) metalimnion, and 3) hypolimnion. The epilimnion is the upper zone of less dense, warmer water in the lake that remains relatively mixed due to wind action and convection. The metalimnion is the middle zone that represents the transition from warm surface water to cooler bottom water. The hypolimnion is the bottom zone of more dense, colder water that is relatively quiescent.

A significant water quality concern that can occur in reservoirs that thermally stratify in the summer is the depletion of dissolved oxygen levels in the hypolimnion. The depletion of dissolved oxygen is attributed to the differing density of water with temperature, the utilization of dissolved oxygen in the decomposition of organic matter, and the oxidation of reduced inorganic substances. When density differences become significant, the deeper colder water is isolated from the surface and re-oxygenation from the atmosphere. In eutrophic lakes, the decomposition of the abundant organic matter can significantly reduce dissolved oxygen in the quiescent hypolimnetic zone. Anoxic conditions in the hypolimnion can result in the release of sediment-bound substances (e.g., phosphorus, metals, sulfides, etc.) as the reduced conditions intensify and result in the production of toxic and caustic substances (e.g., hydrogen sulfide, methane, etc.). Most fish and other intolerant aquatic life cannot inhabit water with less than 4 to 5 mg/l dissolved oxygen for extended periods. These conditions can impact aquatic life in the reservoir and also in waters downstream of the reservoir if its releases through the dam are from a bottom or near-bottom outlet.

1.5.2 SEDIMENTATION

Sedimentation is a process that reduces the usefulness of reservoirs, and the Corps will commonly allow for additional volume to accommodate sedimentation when designing and constructing reservoirs. Reservoir ecology, especially fisheries and benthic aquatic life, can be seriously affected by sedimentation. The reservoir can suffer ecological damage before a volume function such as flood control is impacted. The influx of sediment eliminates fish habitat, adds nutrients, reduces aesthetics, and decreases biodiversity. Managing sediment loading will typically enhance water quality and aquatic

habitat and prolong the recreational use of a reservoir. Reservoir sedimentation can be managed to some extent by constructing sediment basins and wetlands at the headwaters of reservoirs.

1.5.3 SHORELINE EROSION

Shoreline erosion is a major problem occurring on nearly all reservoirs located in areas of erodible soils such as the Midwest. Over 6,000 miles of reservoir shoreline exist at District projects, and it is estimated that over 70 percent of this shoreline is eroding. Some locations have been protected, such as recreational and archaeological sites, but most of the shoreline continues to erode. Continued loss of the shoreline habitat (littoral zone) results in the loss of fishery habitat as well as loss of habitat for other biota such as aquatic vegetation and benthic invertebrates.

1.5.4 BIOACCUMULATION OF CONTAMINANTS IN AQUATIC ORGANISMS

Bioaccumulation is the accumulation of contaminants in the tissue of organisms through any route, including respiration, ingestion, or direct contact with contaminated water or sediment. Bioavailability is the potential for a chemical to be available for biological uptake by an aquatic organism when that organism is processing or encountering a given environmental medium (e.g., the chemicals that can be extracted by the gills from the water as it passes through the respiratory cavity or the chemicals that are absorbed by internal membranes as the organism moves through or ingests sediment). In the aquatic environment, a chemical can exist in three different basic forms that affect availability to organisms: 1) dissolved, 2) sorbed to biotic or abiotic components and suspended in the water column or deposited on the bottom, and 3) incorporated (accumulated) into organisms. Bioconcentration is a process by which there is a net accumulation of a chemical directly from water into aquatic organisms resulting from simultaneous uptake (e.g., by gill or epithelial tissue) and elimination. Biomagnification is the result of the process of bioconcentration and bioaccumulation by which tissue concentrations of bioaccumulated chemicals increase as the chemical passes up through two or more trophic levels. The term implies an efficient transfer of a chemical from food to consumer so that residual concentrations increase systematically from one trophic level to the next.

Bioaccumulation of contaminants can have a direct effect on aquatic organisms. These effects can be chronic (reduced growth, fecundity, etc.) and acute (lethality). The bioaccumulation of contaminants can also be a concern to human health when the contaminated tissue of aquatic organisms is consumed by humans.

1.5.5 OCCURRENCE OF PESTICIDES

Pesticides are widely applied to lands throughout the District. Pesticides recently detected at District Tributary Projects include: acetochlor, alachlor, atrazine, benfluralin, deethylatrazine, deisopropylatrazine, isopropalin, metolachlor, metribuzin, profluralin, prometon, propazine, simazine, and trifluralin. Many of these pesticides do not have State or Federal numeric water quality standards criteria established.

1.5.6 URBANIZATION

Urbanization around many District Projects is occurring at a rapid pace. Tributary reservoirs with urbanizing watersheds include Cherry Creek, Chatfield, and Bear Creek in the Denver, Colorado area; Holmes in the Lincoln, Nebraska area; and Ed Zorinsky, Glen Cunningham, Standing Bear, and Wehrspann in the Omaha, Nebraska area. Urbanization, to a much lesser degree, is occurring at other Tributary Projects in the District.

Construction methods used to develop urban areas disturb the land and allow sediment-laden runoff to impact nearby streams and lakes. Best management practices (BMPs) to minimize construction associated sedimentation damages are used ineffectively in many cases. BMPs to control the impact of construction practices include; sediment retention basins, phased "grading", runoff control (e.g. hay bales, silt fences, vegetative ground cover, terracing, etc), etc. Efforts need to be made to prevent sedimentation from off-project construction activities from causing impacts to District Projects. This could be accomplished by the appropriate State, County, or City agencies working with developers.

Post-construction problems are commonly associated with storm drainage and urban pollution. The conversion of grasslands or forests to roads, rooftops, sidewalks, and other water impervious surfaces make stream flows more variable and increases the frequency of high flow events. In addition, pollutants associated with urban drainage can impact downstream waterbodies. Storm sewer exits can be allowed on project lands provided detention in the form of ponds, swales, or wetlands exist on private property. A developer may be asked to construct a series of detention basins and wetlands to slow downhill flows and provide time for bacterial die-off, chemical degradation, and sediment settling.

1.6 PRIORITIZATION OF DISTRICT-WIDE WATER QUALITY MANAGEMENT ISSUES

The District has identified seven priority issues for water quality management. These priority issues and their relative ranking are listed in Table 1.2.

1.7 PROJECT-SPECIFIC WATER QUALITY MANAGEMENT ISSUES AT THE TRIBUTARY PROJECTS

1.7.1 SECTION 303(D) LISTINGS OF IMPAIRED WATERS

Under Section 303(d) of the Federal Clean Water Act (CWA), Tribes and States, with the delegated authority from the U.S. Environmental Protection Agency (EPA), are required to prepare a periodic list of impaired waters [i.e., Section 303(d) list]. Impaired waters refer to those waterbodies where it has been determined that technology-based effluent limitations required by Section 301 of the CWA are not stringent enough to attain and maintain applicable water quality standards. Tribes and States, as appropriate, are required to establish and implement Total Maximum Daily Loads (TMDLs) for waterbodies on their Section 303(d) lists.

1.7.2 FISH CONSUMPTION ADVISORIES

Fish are capable of accumulating many toxic substances in excess of 1,000 times the concentrations found in surface waters. The public has expressed concerns on whether fish caught from District Project waters are safe to consume. It is important that answers to public health concerns be based on substantiated knowledge of toxicants in fish fillets and the public health risks associated with measured toxicant concentrations. This type of information can be used by States when considering the issuance of fish consumption advisories. Fish consumption advisories have been issued for fish caught from certain District Project waters. Mercury is the most prevalent contaminant leading to the issuance of fish consumption advisories at District Projects.

Table 1.2. Priority water quality management issues for the District's Water Quality Management Program.

	Missouri River Mainstem System Water Quality Management Issues
➢	Determine how regulation of the Missouri River Mainstem System (Mainstem System) dams affects water quality in the impounded reservoir and downstream river. Utilize the CE-QUAL-W2 hydrodynamic and water quality model to facilitate this effort.
➢	Evaluate how eutrophication is progressing in the Mainstem System reservoirs, especially regarding the expansion of anoxic conditions in the hypolimnion during summer stratification.
➢	Determine how flow regime, especially the release of water from Mainstem System projects, affects water quality in the Missouri River.
➢	Determine how current water quality conditions in the Missouri River (e.g., water temperature, turbidity, etc.) may be affecting pallid sturgeon populations in the Missouri River system.
	District-Wide Water Quality Management Issues
➢	Provide water quality information to support Corps reservoir regulation elements for effective surface water quality and aquatic habitat management.
➢	Provide water quality information and technical support to the Tribes and States in the development of their Section 303(d) lists and development and implementation of TMDLs at District Projects.
➢	Identify existing and potential surface water quality problems at District Projects and develop and implement appropriate solutions.
➢	Evaluate surface water quality conditions and trends at District Projects.

1.7.3 SUMMARY OF PROJECT-SPECIFIC TMDL CONSIDERATIONS, FISH CONSUMPTION ADVISORIES, AND OTHER WATER QUALITY MANAGEMENT ISSUES

Table 1.3 summarizes TMDL considerations, fish consumption advisories, and other water quality management issues applicable to District Tributary Projects. The impaired uses and pollutant/stressors (i.e., TMDL considerations) and identified contamination (i.e., Fish Consumption Advisories) identified in Table 1.3 are taken directly from the appropriate State 303(d) impaired waters listings and issued fish consumption advisories. They are provided for information purposes and are not based on water quality monitoring conducted by the District. The listed other water quality management issues in Table 1.3 were identified by the District based on District water quality monitoring and water quality management concerns. Water quality management issues at specific Tributary Projects are assessed in further detail in any Project-Specific Reports prepared by the District or State-prepared TMDL plans developed for any State-listed impaired waterbody.

Table 1.3. Summary of project-specific water quality management issues and concerns at District Tributary Projects.

Project Area	TMDL Considerations*				Fish Consumption Advisories		Other Water Quality Management Issues
	On 303(d) List	Impaired Uses	Pollutant/Stressor	TMDL Completed	Advisory in Effect	Identified Contamination	
Colorado Tributary Projects:							
Bear Creek Reservoir	Yes**	Aquatic Life	Dissolved Oxygen**	No	No		Site specific phosphorus and chlorophyll-a water quality criteria
Chatfield Reservoir	No	-----	-----	-----	No		Site specific phosphorus and chlorophyll-a water quality criteria
Cherry Creek Reservoir	No	-----	-----	-----``	No		Site specific phosphorus and chlorophyll-a water quality criteria
Nebraska Tributary Projects:							
Bluestem Reservoir	Yes	Aquatic Life, Aesthetics	Sediment, Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)	No	No		TMDL to be developed
Branched Oak Reservoir	Yes	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)	No	No		TMDL to be developed
Conestoga Reservoir	Yes	Aquatic Life, Aesthetics, Recreation	Algae Toxins, Sediment, Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)	No	No		TMDL to be developed
East Twin Reservoir	Yes	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)	No	No		TMDL to be developed
Ed Zorinsky Reservoir	Yes	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen) Mercury (Fish Tissue)	Yes	Yes	Mercury	TMDLs for nutrients and sediment approved (2002)
Glenn Cunningham Reservoir	No***	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)	No	No		Renovation project completed in 2008
Holmes Reservoir	No***	Aquatic Life	High pH, Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)	Yes	No		TMDLs for nutrients and sediment approved (2003) Renovation project completed in 2005
Olive Creek Reservoir	Yes	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Ammonia, Arsenic, High pH, Low Dissolved Oxygen	No	No		TMDL to be developed
Pawnee Reservoir	Yes	Aquatic Life, Aesthetics, Recreation	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Algae Toxins, Arsenic, Sediment	Yes/No	No		TMDL for sediment approved (2001)
Stagecoach Reservoir	Yes	Aesthetics, Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Sediment	No	No		TMDL to be developed
Standing Bear Reservoir	Yes	Aesthetics, Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Mercury (Fish Tissue), Sediment	Yes	Yes	Mercury	TMDLs for nutrients and sediment approved (2003)
Wagon Train Reservoir	Yes	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Arsenic, Mercury (Fish Tissue)	Yes	Yes		TMDLs for nutrients and sediment approved (2002)
Wehrspann Reservoir	Yes	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Mercury (Fish Tissue)	No	Yes	Mercury	TMDL to be developed

West Twin Reservoir	Yes	Aquatic Life	Ammonia, Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)	No	No		TMDL to be developed
Yankee Hill Reservoir	No***	-----	High pH	Yes	No		TMDLs for nutrients and sediment approved (2002) Renovation project completed in 2006
North Dakota Tributary Projects:							
Bowman-Haley Reservoir	No	-----	-----	-----	Yes	Mercury	Algal blooms
Pipestem Reservoir	Yes	Recreation	Nutrients/Eutrophication Biological Indicators	No	Yes	Mercury	Fully Supported But Threatened
South Dakota Tributary Projects:							
Cold Brook	Yes	Coldwater Fishery	Water Temperature	No	No		Natural Condition

* Information taken from published State Total Maximum Daily Load (TMDL) Section 303(d) reports and listings as of October 1, 2011.

** Identified on Colorado's Monitoring and Evaluation List. Water quality problem suspected, but uncertainty exists based on available data.

*** Category 4R – Waterbody data exceeds the impairment threshold however a TMDL may not be needed. The category will only be used for nutrient assessments in new or renovated lakes and reservoirs. Newly filled reservoirs usually go through a period of trophic instability – a trophic upsurge followed by the trophic decline. Erroneous water quality assessments are likely to occur during this period. To account for this, all new or renovated reservoirs will be placed in this category for a period not to exceed eight years following the fill or re-fill process. After the eighth year monitoring data will be assessed and the waterbody will be appropriately placed into category 1, 2, or 5.

2 LIMNOLOGICAL PROCESSES IN RESERVOIRS

All of the Tributary Projects in the District involve the operation and maintenance of a reservoir and the regulation of flows discharged from reservoirs. Much of the water quality monitoring conducted by the District is done to determine existing water quality conditions and identify water quality management concerns at these reservoirs. A basic understanding of the limnological processes that occur in reservoirs is needed to understand the water quality information provided in this report. The following discussion provides a basic overview of limnological processes that occur in reservoirs.

2.1 VERTICAL AND LONGITUDINAL WATER QUALITY GRADIENTS

The annual temperature distribution represents one of the most important limnological processes occurring within a reservoir. Thermal variation in a reservoir results in temperature-induced density stratification, and an understanding of the thermal regime is essential to water quality assessment. Deep, temperate-zone lakes typically completely mix from the surface to the bottom twice a year (i.e., dimictic). Temperate-zone dimictic lakes exhibit thermally-induced density stratification in the summer and winter months that is separated by periods of "turnover" in the spring and fall. This stratification typically occurs through the interaction of wind and solar insolation at the lake surface and creates density gradients that can influence lake water quality. During the summer, solar insolation has its highest intensity and the reservoir becomes stratified into three zones: 1) epilimnion, 2) metalimnion, and 3) hypolimnion.

Epilimnion: The epilimnion is the upper zone that consists of the less dense, warmer water in the reservoir. It is fairly turbulent since its thickness is determined by the turbulent kinetic energy inputs (e.g., wind, convection, etc.), and a relatively uniform temperature distribution throughout this zone is maintained.

Metalimnion: The metalimnion is the middle zone that represents the transition from warm surface water to colder bottom water. There is a distinct temperature gradient through the metalimnion. The metalimnion contains the thermocline that is the plane or surface of maximum temperature rate change.

Hypolimnion: The hypolimnion is the bottom zone of more dense, colder water that is relatively quiescent. Bottom withdrawal or fluctuating water levels in reservoirs, however, may significantly increase hypolimnetic mixing.

Long, dendritic reservoirs, with tributary inflows located a considerable distance from the outflow and unidirectional flow from headwater to dam develop gradients in space and time (USACE, 1987). Although these gradients are continuous from headwater to dam, three characteristic zones result: a riverine zone, a zone of transition, and a lacustrine zone (USACE, 1987).

Riverine Zone: The riverine zone is relatively narrow, well mixed, and although water current velocities are decreasing, advective forces are still sufficient to transport significant quantities of suspended particles, such as silts, clays, and organic particulate. Light penetration in this zone is minimal and may be the limiting factor that controls primary productivity in the water column. The decomposition of tributary organic loadings often creates a significant oxygen demand, but an aerobic environment is maintained because the riverine zone is generally shallow and well mixed. Longitudinal dispersion may be an important process in this zone.

Zone of Transition: Significant sedimentation occurs through the transition zone, with a subsequent increase in light penetration. Light penetration may increase gradually or abruptly, depending on the flow regime. At some point within the mixed layer of the zone of transition, a

compensation point between the production and decomposition of organic matter should be reached. Beyond this point, production of organic matter within the reservoir mixed layer should begin to dominate.

Lacustrine Zone: The lacustrine zone is characteristic of a lake system. Sedimentation of inorganic particulate is low. Light penetration is sufficient to promote primary production, with nutrient levels the limiting factor and production of organic matter exceeds decomposition within the mixed layer. Entrainment of metalimnetic and hypolimnetic water, particulate, and nutrients may occur through internal waves or wind mixing during the passage of large weather fronts. Hypolimnetic mixing may be more extensive in reservoirs than "natural" lakes because of bottom withdrawal at dams. In addition, a dam intake structure may simultaneously remove water from the hypolimnion and metalimnion.

When tributary inflow enters a reservoir, it displaces the reservoir water. If there is no density difference between the inflow and reservoir waters, the inflow will mix with the reservoir water as the inflow water moves toward the dam. However, if there are density differences between the inflow and reservoir waters, the inflow moves as a density current in the form of overflows, interflows, or underflows. Internal mixing is the term used to describe mixing within a reservoir from such factors as wind, Langmuir circulation, convection, Kelvin-Helmholtz instabilities, and outflow (USACE, 1987).

2.2 CHEMICAL CHARACTERISTICS OF RESERVOIR PROCESSES

2.2.1 CONSTITUENTS

Some of the most important chemical constituents in reservoir waters that affect water quality are needed by aquatic organisms for survival. These include oxygen, carbon, nitrogen, and phosphorus. Other important constituents are silica, manganese, iron, and sulfur.

Dissolved oxygen: Oxygen is a fundamental chemical constituent of waterbodies that is essential to the survival of aquatic organisms and is one of the most important indicators of reservoir water quality conditions. The distribution of dissolved oxygen (DO) in reservoirs is a result of dynamic transfer processes from the atmospheric and photosynthetic sources to consumptive uses by the aquatic biota. The resulting distribution of DO in the reservoir water strongly affects the solubility of many inorganic chemical constituents. Often, water quality control or management approaches are formulated to maintain an aerobic, or oxic (i.e., oxygen-containing), environment. Oxygen is produced by aquatic plants (phytoplankton and macrophytes) and is consumed by aquatic plants, other biological organisms, and chemical oxidations. In reservoirs, the DO demand may be divided into two separate but highly interactive fractions: sediment oxygen demand (SOD) and water column oxygen demand.

Sediment oxygen demand: The SOD is typically highest in the upstream area of the reservoir just below the headwaters. This is an area of transition from riverine to lake characteristics. It is relatively shallow but stratifies. The loading and sedimentation of organic matter is high in this transition area and, during stratification, the hypolimnetic DO to satisfy this demand can be depleted. If anoxic conditions develop, they generally do so in this area of the reservoir and progressively move toward the dam during the stratification period. The SOD is relatively independent of DO when DO concentrations in the water column are greater than 3 to 4 mg/l but becomes limited by the rate of oxygen supply to the sediments.

Water column oxygen demand: A characteristic of many reservoirs is a metalimnetic minimum in DO concentrations, or negative heterograde oxygen curve (Figure 2.1). Density interflows not only transport oxygen-demanding material into the metalimnion, but can also entrain reduced chemicals from the upstream anoxic area and create additional oxygen demand. Organic matter and organisms from the mixed layer settle at slower rates in the metalimnion because of increased

viscosity due to lower temperatures. Since this labile organic matter remains in the metalimnion for a longer time period, decomposition occurs over a longer time, exerting a higher oxygen demand. Metalimnetic oxygen depletion is an important process in deep reservoirs. A hypolimnetic oxygen demand generally starts at the sediment/water interface unless underflows contribute organic matter that exerts a significant oxygen demand. In addition to metalimnetic DO depletion, hypolimnetic DO depletion also is important in shallow, stratified reservoirs since there is a smaller hypolimnetic volume of oxygen to satisfy oxygen demands than in deeper reservoirs.

Dissolved oxygen distribution: Two basic types of vertical DO distribution may occur in the water column: an orthograde and clinograde DO distribution (Figure 2.1). In the orthograde distribution, DO concentration is a function primarily of temperature, since DO consumption is limited. The clinograde DO profile is representative of more productive, nutrient-rich reservoirs where the hypolimnetic DO concentration progressively decreases during stratification and can occur during both summer and winter stratification periods.

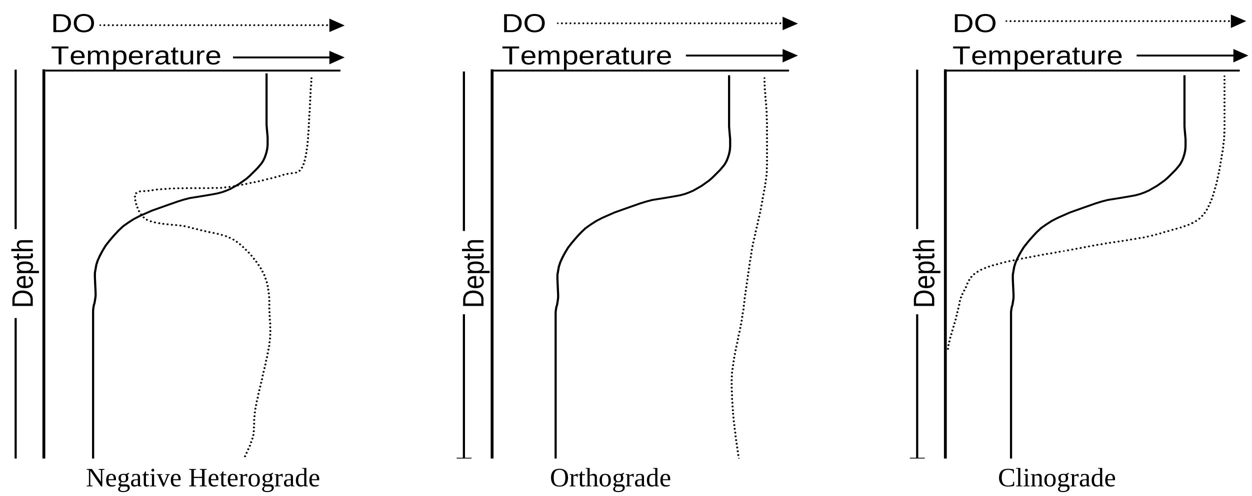

Figure 2.1. Vertical oxygen concentrations possible in thermally stratified lakes.

Inorganic carbon: Inorganic carbon represents the basic building block for the production of organic matter by plants. Inorganic carbon can also regulate the pH and buffering capacity or alkalinity of aquatic systems. Inorganic carbon exists in a dynamic equilibrium in three major forms: carbon dioxide (CO_2), bicarbonate ions (HCO_3), and carbonate ions (CO_3). Carbon dioxide is readily soluble in water and some CO_2 remains in a gaseous form, but the majority of the CO_2 forms carbonic acid that dissociates rapidly into HCO_3 and CO_3 ions. This dissociation results in a weakly alkaline system (i.e., pH $\approx$ 7.1 or 7.2). There is an inverse relationship between pH and CO_2. The pH increases when aquatic plants (phytoplankton or macrophytes) remove CO_2 from the water to form organic matter through photosynthesis during the day. During the night when aquatic plants respire and release CO_2, the pH decreases. The extent of this pH change provides an indication of the buffering capacity of the system. Weakly buffered systems with low alkalinities (i.e., <500 microequivalents per liter) experience larger shifts in pH than well-buffered systems (i.e., >1,000 microequivalents per liter).

Nitrogen: Nitrogen is important in the formulation of plant and animal protein. Nitrogen, similar to carbon, also has a gaseous form. Many species of cyanobacteria can use or fix elemental or gaseous N_2 as a nitrogen source. The most common forms of nitrogen in aquatic systems are ammonia (NH_3-N), nitrite

(NO_2-N), and nitrate (NO_3-N). All three forms are transported in water in a dissolved phase. Ammonia results primarily from the decomposition of organic matter. Nitrite is primarily an intermediate compound in the oxidation or nitrification of ammonia to nitrate, while nitrate is the stable oxidation state of nitrogen and represents the other primary inorganic nitrogen form besides NH_3 used by aquatic plants.

Phosphorus: Phosphorus is used by both plants and animals to form enzymes and vitamins and to store energy in organic matter. Phosphorus has received considerable attention as the nutrient controlling algal production and densities and associated water quality problems. The reasons for this emphasis are: phosphorus tends to limit plant growth more than the other major nutrients; phosphorus does not have a gaseous phase and ultimately originates from the weathering of rocks; removal of phosphorus from point sources can reduce the growth of aquatic plants; and the technology for removing phosphorus is more advanced and less expensive than nitrogen removal. Phosphorus is generally expressed in terms of the chemical procedures used for measurement: total phosphorus, particulate phosphorus, dissolved or filterable phosphorus, and soluble reactive phosphorus. Phosphorus is a very reactive element; it reacts with many cations such as iron and calcium and is readily sorbed on particulate matter such as clays, carbonates, and inorganic colloids. Since phosphorus exists in a particulate phase, sedimentation represents a continuous loss from the water column to the sediment. Sediment phosphorus, then, may exhibit longitudinal gradients in reservoirs similar to sediment silt/clay gradients. Phosphorus contributions from sediment under anoxic conditions and macrophyte decomposition are considered internal phosphorus sources or loads, and are in a chemical form readily available for plankton uptake and use. Internal phosphorus loading can represent a major portion of the total phosphorus budget.

Silica: Silica is an essential component of diatom algal frustules or cell walls. Silica uptake by diatoms can markedly reduce silica concentrations in the epilimnion and initiate a seasonal succession of diatom species. When silica concentrations decrease below 0.5 mg/l, diatoms generally are no longer competitive with other phytoplankton species.

Other nutrients: Iron, manganese, and sulfur concentrations generally are adequate to satisfy plant nutrient requirements. Oxidized iron (III) and manganese (IV) are quite insoluble in water and occur in low concentrations under aerobic conditions. Under aerobic conditions, sulfur usually is present as sulfate.

2.2.2 ANAEROBIC (ANOXIC) CONDITIONS

When dissolved oxygen concentrations in the hypolimnion are reduced to approximately 2 to 3 mg/l, the oxygen regime at the sediment/water interface is generally considered hypoxic, and anaerobic processes begin to occur in the sediment interstitial water. Nitrate reduction to ammonium and/or N_2O or N_2 (denitrification) is considered to be the first phase of the anaerobic process and places the system in a slightly reduced electrochemical state. Ammonium-nitrogen begins to accumulate in the hypolimnetic water. The presence of nitrate prevents the production of additional reduced forms such as manganese (II), iron (II), or sulfide species. Denitrification probably serves as the main mechanism for removing nitrate from the hypolimnion. Following the reduction or denitrification of nitrate, manganese species are reduced from insoluble forms (i.e., Mn (IV)) to soluble manganous forms (i.e., Mn (II)), which diffuse into the overlying water column. Nitrate reduction is an important step in anaerobic processes since the presence of nitrate in the water column will inhibit manganese reduction. As the electrochemical potential of the system becomes further reduced, iron is reduced from the insoluble ferric (III) form to the soluble ferrous (II) form, and begins to diffuse into the overlying water column. Phosphorus, in many instances, is also transported in a complexed form with insoluble ferric (III) species so the reduction and solubilization of iron also result in the release and solubilization of phosphorus into the water column. The sediments may serve as a major phosphorus source during anoxic periods and a phosphorus sink during aerobic periods. During this period of anaerobiosis, microorganisms also are decomposing organic

matter into lower molecular weight acids and alcohols such as acetic, fulvic, humic, and citric acids and methanol. These compounds may also serve as trihalomethane precursors (low-molecular weight organic compounds in water; i.e., methane, formate acetate), which, when subject to chlorination during water treatment, form trihalomethanes, or THMs (carcinogens). As the system becomes further reduced, sulfate is reduced to sulfide, which begins to appear in the water column. Sulfide will readily combine with soluble reduced iron (II), however, to form insoluble ferrous sulfide, which precipitates out of solution. If the sulfate is reduced to sulfide and the electrochemical potential is strongly reducing, methane formation from the reduced organic acids and alcohols may occur. Consequently, water samples from anoxic depths will exhibit these chemical characteristics.

Anaerobic processes are generally initiated in the upstream portion of the hypolimnion where organic loading from the inflow is relatively high and the volume of the hypolimnion is minimal, so oxygen depletion occurs rapidly. Anaerobic conditions are generally initiated at the sediment/water interface and gradually diffuse into the overlying water column and downstream toward the dam. Anoxic conditions may also develop in a deep pocket near the dam due to decomposition of autochthonous organic matter settling to the bottom. This anoxic pocket, in addition to expanding vertically into the water column, may also move upstream and eventually meet the anoxic zone moving downstream.

Anoxic conditions are generally associated with the hypolimnion, but anoxic conditions may occur in the metalimnion. The metalimnion may become anoxic due to microbial respiration and decomposition of plankton settling into the metalimnion, microbial metabolism of organic matter entering as an interflow, or through entrainment of anoxic hypolimnetic water from the upper portion of the reservoir.

2.3 BIOLOGICAL CHARACTERISTICS AND PROCESSES

2.3.1 MICROBIOLOGICAL

The microorganisms associated with reservoirs may be categorized as pathogenic or nonpathogenic. Pathogenic microorganisms are of a concern from a human health standpoint and may limit recreational and other uses of reservoirs. Nonpathogenic microorganisms are important in that they often serve as decomposers of organic matter and are a major source of carbon and energy for a reservoir. Microorganisms generally inhabit all zones of the reservoir as well as all layers. Seasonally high concentrations of bacteria will occur during the warmer months, but they can be diluted by high discharges. Anaerobic conditions enhance growth of certain bacteria while aeration facilitates the use of bacterial food sources. Microorganisms, bacteria in particular, are responsible for mobilization of contaminants from sediments.

2.3.2 PHOTOSYNTHESIS

Oxygen is a by-product of aquatic plant photosynthesis, which represents a major source of oxygen for reservoirs during the growing season. Oxygen solubility is less during the period of higher water temperatures, and diffusion may also be less if wind speeds are lower during the summer than the spring or fall. Biological activity and oxygen demand typically are high during thermal stratification, so photosynthesis may represent a major source of oxygen during this period. Oxygen supersaturation in the euphotic zone can occur during periods of high photosynthesis.

2.3.3 PLANKTON

Phytoplankton influence dissolved oxygen and suspended solids concentrations, transparency, taste and odor, aesthetics, and other factors that affect reservoir uses and water quality objectives.

Phytoplankton are a primary source of organic matter production and form the base of the autochthonous food web in many reservoirs since fluctuating water levels may limit macrophyte and periphyton production. Phytoplankton can be generally grouped as diatoms, green algae, cyanobacteria (i.e., blue-green algae), or cryptomonad algae. Chlorophyll *a* represents a common variable used to estimate phytoplankton biomass.

Seasonal succession of phytoplankton species is a natural occurrence in reservoirs. The spring assemblage is usually dominated by diatoms and cryptomonads. Green algae usually succeed the diatoms as silica depletion in the photic zone occurs with increased settling as viscosity decreases because of increased temperatures. Decreases in nitrogen or a decreased competitive advantage for carbon at higher pH may result in cyanobacteria succeeding the green algae during summer and fall. Diatoms generally return in the fall, but cyanobacteria, greens, or diatoms may cause algae blooms following fall turnover when hypolimnetic nutrients are mixed throughout the water column. The general pattern of seasonal succession of phytoplankton is fairly constant from year to year. However, hydrologic variability, such as increased mixing and delay in the onset of stratification during cool, wet spring periods, can maintain diatoms longer in the spring and shift or modify the successional pattern of algae in reservoirs.

Phytoplankton grazers can reduce the abundance of algae and alter their successional patterns. Some phytoplankton species are consumed and assimilated more readily and are preferentially selected by consumers. Single-celled diatom and green algae species are readily consumed by zooplankton, while filamentous cyanobacteria are avoided by zooplankters. Altering the fish population can result in a change in the zooplankton population that can affect the phytoplankton population.

2.3.4 ORGANIC CARBON AND DETRITUS

Total organic carbon (TOC) is composed of dissolved organic carbon (DOC) and particulate organic carbon (POC). Detritus represents that portion of the POC that is nonliving. Nearly all the TOC of natural waters consists of DOC and detritus, or dead POC. The processes of decomposition and consumption of TOC are important in reservoirs and can have a significant affect on water quality.

DOC and POC are decomposed by microbial organisms. This decomposition exerts an oxygen demand that can remove dissolved oxygen from the water column. During stratification, the metalimnion and hypolimnion become relatively isolated from sources of dissolved oxygen, and depletion can occur through organic decomposition. There are two major sources of this organic matter: allochthonous (i.e., produced outside the reservoir and transported in) and autochthonous (i.e., produced within the reservoir). Allochthonous organic carbon in small streams may be relatively refractory since it consists of decaying terrestrial vegetation that has washed or fallen into the stream. Larger rivers, however, may contribute substantial quantities of riverine algae or periphyton that decompose rapidly and can exert a significant oxygen demand. Autochthonous sources include dead plankton settling from the mixed layers and macrophyte fragments and periphyton transported from the littoral zone. These sources are also rapidly decomposed.

POC and DOC absorbed onto sediment particles may serve as a major food source for aquatic organisms. The majority of the phytoplankton production enters the detritus food web with a minority being grazed by primary consumers (USACE, 1987). While autochthonous production is important in reservoirs, typically as much as three times the autochthonous production may be contributed by allochthonous material (USACE, 1987).

2.4 BOTTOM WITHDRAWAL RESERVOIRS

Bottom withdrawal structures are located near the deepest part of a reservoir. Bottom withdrawal removes hypolimnetic water and nutrients and may promote movement of interflows or underflow into the hypolimnion. They release cold water from the deep portion of the reservoir; however, this water may be anoxic during periods of stratification. Bottom outlets can cause density interflows or underflows (e.g., flow laden with sediment or dissolved solids) through the reservoir and generally provide little or no direct control over release water quality.

3 TRIBUTARY PROJECTS WATER QUALITY MONITORING

3.1 COLORADO TRIBUTARY PROJECTS

The District has not conducted water quality monitoring at any of the three District Tributary Projects in Colorado since 2002. At each of these reservoirs (i.e., Bear Creek, Chatfield, and Cherry Creek), local Watershed Authorities have been established to improve and protect water quality. As part of these efforts, the Watershed Authorities have established water quality monitoring networks at each of the three reservoirs. After reviewing the water quality monitoring efforts of the three Watershed Authorities, the District determined that its water quality information needs can be met though the use of the water quality data collected through the Bear Creek, Chatfield, and Cherry Creek Watershed Authorities.

3.2 NEBRASKA TRIBUTARY PROJECTS

3.2.1 AMBIENT RESERVOIR WATER QUALITY MONITORING

The District has conducted fixed-station ambient surface water quality monitoring at all the Nebraska tributary reservoirs. Some reservoirs have been monitored for the past 30 years. Since 2003, the District has cooperated with the Nebraska Department of Environmental Quality (NDEQ) to monitor ambient surface water quality conditions at all the Papillion Creek tributary reservoirs (i.e., Glenn Cunningham, Standing Bear, Wehrspann, and Ed Zorinsky) and Salt Creek tributary reservoirs (i.e., Bluestem, Branched Oak, Conestoga, East Twin, Holmes, Olive Creek, Pawnee, Stagecoach, Wagon Train, West Twin, and Yankee Hill).

Ambient surface water quality monitoring at the Nebraska tributary reservoirs included monthly sampling (May through September) at three longitudinal locations on the reservoirs: 1) near-dam, 2) middle reaches, and 3) upstream reaches. Where a discrete submerged creek channel still existed, the monitoring site was located in the deepwater area over the submerged creek channel. Water quality monitoring at the near-dam location included field measurements for depth profiling and water transparency, and collection of near-surface and near-bottom grab samples for laboratory analysis. Water quality monitoring at the mid-reservoir and up-reservoir locations included field measurements for depth profiling and water transparency. Depth profiles in ½-meter increments were determined for temperature, dissolved oxygen, pH, conductivity, ORP, turbidity, and chlorophyll *a*. Near-surface grab samples were analyzed for alkalinity, nitrate/nitrite, total ammonia, Kjeldahl nitrogen, total phosphorus, orthophosphorus, total suspended solids, chlorophyll *a*, pesticides, and various metals. Except for chlorophyll <u>*a*</u>, pesticides, and various metals, near-bottom samples grab samples were analyzed for the same parameters.

3.2.2 MONITORING AT SWIMMING BEACHES

The District has cooperated with the NDEQ to monitor bacteria and cyanobacteria toxin levels present at swimming beaches and major recreational use areas at the Nebraska tributary reservoirs over the past 5 years. Reservoirs that were sampled include: Glenn Cunningham, Bluestem, Branched Oak, Conestoga, Pawnee, and Wagon Train. Weekly grab samples were collected from May to September and analyzed for *E. coli* bacteria and the cyanobacteria toxin microcystin. The bacteria monitoring was conducted to meet a 6-hour holding time for collected samples.

3.2.3 INFLOW MONITORING DURING RUNOFF CONDITIONS

Since 2003, the District has cooperated with the NDEQ to monitor water quality conditions of major inflows under runoff conditions at all the Nebraska tributary reservoirs. Up to six runoff events from April through September were sampled annually at each of the reservoirs. Near-surface runoff grab samples were collected from a bridge or stream bank and analyzed for suspended solids, total Kjeldahl nitrogen, nitrate/nitrate, total ammonia, total phosphorus, acetochlor, alachlor, atrazine, and metolachlor.

3.3 NORTH DAKOTA TRIBUTARY PROJECTS

The District has monitored ambient water quality conditions over the past 30 years at the two Tributary Projects in North Dakota – Bowman-Haley and Pipestem. During the past 5 years, ambient monitoring of the reservoirs was conducted in 2007 and 2010. Ambient water quality monitoring at Bowman-Haley and Pipestem Reservoirs is now on a 3-year rotating cycle with the next ambient monitoring scheduled for 2013. The ambient monitoring included monthly sampling (May through September) at near-dam, mid-reservoir, and up-reservoir deepwater locations. Water quality monitoring at the near-dam location included field measurements for depth profiling and water transparency and collecting near-surface and near-bottom water samples for laboratory physicochemical analysis. Water quality monitoring at the mid-reservoir and up-reservoir locations included field measurements for depth profiling and water transparency. Depth profiles in 1/2-meter increments were determined for temperature, dissolved oxygen, pH, conductivity, ORP, turbidity, and chlorophyll *a*. Near-surface grab samples were analyzed for alkalinity, nitrate/nitrite, total ammonia, Kjeldahl nitrogen, total phosphorus, orthophosphorus, total suspended solids, total organic carbon, chlorophyll *a*, pesticides, and various metals. Except for chlorophyll *a*, pesticides, and various metals, near-bottom samples grab samples were analyzed for the same parameters.

3.4 SOUTH DAKOTA TRIBUTARY PROJECTS

The District has monitored ambient water quality conditions at the two Tributary Projects in South Dakota – Cold Brook and Cottonwood Springs. Ambient water quality monitoring at the two reservoirs is now on a 3-year rotating cycle with the next monitoring scheduled for 2012. Since 2000 monitoring at the reservoirs occurred in 2000-2003 and 2008. Ambient water quality monitoring was scheduled for both reservoirs in 2005, but was cancelled due low water conditions and access problems. The District conducted water quality monitoring at Cold Brook Reservoir in 2008; however, Cottonwood Springs Reservoir was again not sampled in 2008 due to low water conditions. Scheduled ambient water quality monitoring includes monthly sampling (May through September) at near-dam, mid-reservoir, and up-reservoir locations. Water quality monitoring at the near-dam location includes field measurements for depth profiling and water transparency and collecting near-surface and near-bottom water samples for laboratory physicochemical analysis. Water quality monitoring at the mid-reservoir and up-reservoir locations include field measurements for depth profiling and water transparency. Depth profiles in ½-meter increments are determined for temperature, dissolved oxygen, pH, conductivity, ORP, turbidity, and chlorophyll *a*. Near-surface grab samples are analyzed for alkalinity, nitrate/nitrite, total ammonia, Kjeldahl nitrogen, total phosphorus, orthophosphorus, total suspended solids, total organic carbon, chlorophyll *a*, pesticides, and various metals. Except for chlorophyll *a*, pesticides, and various metals, near-bottom samples grab samples are analyzed for the same parameters.

4 WATER QUALITY ASSESSMENT METHODS

4.1 EXISTING WATER QUALITY

In this report existing water quality is based on the "Sufficient and Credible Data Requirements" identified by the appropriate States in their methodologies for water quality assessment for development of the State's integrated water quality reports. The State integrated water quality reports follow the U.S. Environmental Protection Agency's Consolidated Assessment and Listing Methodology (CALM) guidance provided to the States for preparing their water quality reports pursuant to Sections 305(b) and 303(d) of the Federal Clean Water Act (CWA). States have identified "age restrictions" for data to insure credible assessment of existing water quality conditions. The four States where District Tributary Projects are located have identified the following data age restrictions for credible assessment of existing water quality conditions: Colorado (not applicable), Nebraska (5 years), North Dakota (10 years), and South Dakota (9 years).

4.1.1 STATISTICAL SUMMARY AND COMPARISON TO APPLICABLE NUMERIC WATER QUALITY STANDARDS CRITERIA

Statistical analyses were performed on the water quality monitoring data collected at the Tributary Projects. Descriptive statistics were calculated to describe central tendencies and the range of observations in existing water quality. Monitoring results were compared to applicable water quality standards criteria established by the appropriate States pursuant to the Federal CWA. Tables were constructed that list the parameters measured; number of observations; and the mean, median, minimum, and maximum of the data collected. The constructed tables also list the water quality standards criteria applicable to the individual parameters and the frequency that these criteria were not met.

4.1.2 SPATIAL VARIATION IN RESERVOIR WATER QUALITY CONDITIONS

4.1.2.1 <u>Longitudinal Variation</u>

Depending on their length, shape, mixing characteristics, and residence time, reservoirs can experience significant longitudinal variation in water quality. The longitudinal variation in smaller reservoirs is greatly influenced by the water quality characteristics of inflow water during significant runoff events.

4.1.2.1.1 Contour Plots

Longitudinal contour plots were constructed when adequate depth-profile measurements were collected along the length of a reservoir. At these reservoirs longitudinal contour plots were constructed for water temperature, dissolved oxygen, and turbidity. Oxidation-reduction potential (ORP) and pH longitudinal contour plots were also constructed where hypoxic dissolved oxygen conditions were present. For this report hypoxic conditions are defined as dissolved oxygen concentrations ≤ 2.5 mg/l and anoxic conditions are defined as dissolved oxygen concentrations ≤ 0.5 mg/l. The longitudinal contour plots were constructed using the "Hydrologic Information Plotting Program" included in the "Data Management and Analysis System for Lakes, Estuaries, and Rivers" (DASLER-X) software developed by HydroGeoLogic, Inc. (Hydrogeologic Inc., 2005).

4.1.2.1.2 Box Plots

Longitudinal box plots were constructed from Secchi depth measurements collected within reservoirs. Box plots for monitored sites within a reservoir were plotted relative to their location within the reservoir.

4.1.2.2 Vertical Variation in Water Quality

Depending on their depth and bathymetry, reservoirs can experience thermally-induced density stratification in the summer. The denser water near the reservoir bottom inhibits mixing of the hypolimnion with the less dense water near the reservoir surface. This, coupled with the decomposition of organic matter at the reservoir bottom, can lead to the development of hypoxic conditions in the hypolimnion. Under hypoxic conditions anaerobic processes begin to occur that results in the reduction of oxidized compounds (e.g., denitrification, etc.). Strongly reduced conditions can develop if hypoxic conditions become anoxic and persist. This can lead to significant vertical variation in water quality conditions.

4.1.2.2.1 Depth Profile Plots

Measured water temperature and dissolved oxygen depth profiles were plotted for measurements taken during the summer at the near-dam, deepwater ambient monitoring locations. Depth profiles measured within the State defined "age restrictions" were included. The plots were reviewed to assess the occurrence of thermal stratification and hypolimnetic dissolved oxygen degradation. Depth profiles were also plotted for ORP and pH if hypoxic conditions were present.

4.1.2.2.2 Comparison of Near-Surface and Near-Bottom Water Quality Conditions

The variation of selected parameters with depth was evaluated by comparing paired near-surface and near-bottom samples collected when hypoxia was present. The paired samples compared were collected at sites for a reservoir were hypoxic conditions were monitored near the reservoir bottom. The parameters compared included water temperature, dissolved oxygen, ORP, pH, total ammonia, nitrate-nitrite, alkalinity, total phosphorus, and orthophosphorus.

4.1.3 TROPHIC STATUS

A trophic state index (TSI) was calculated, as described by Carlson (1977). TSI values were determined from Secchi depth transparency, total phosphorus, and chlorophyll *a* measurements. Values for these three parameters were converted to an index number ranging from 0 to 100 according to the following equations:

TSI(Secchi Depth) = TSI(SD) = 10[6 - (ln SD/ln 2)]
TSI(Chlorophyll *a*) = TSI(Chl) = 10[6 - ((2.04-0.68 ln Chl)/ln 2)]
TSI(Total Phosphorus) = TSI(TP) = 10[6 – (ln (48/TP)/ln 2)]

Accurate TSI values from total phosphorus depend on the assumptions that phosphorus is the major limiting factor for algal growth and that the concentrations of all forms of phosphorus present are a function of algal biomass. Accurate TSI values from Secchi depth transparency depend on the assumption that water clarity is primarily limited by phytoplankton biomass. Carlson indicates that the chlorophyll TSI value may be a better indicator of a lake's trophic conditions during mid-summer when algal productivity is at its maximum, while the total phosphorus TSI value may be a better indicator in the spring and fall when algal biomass is below its potential maximum. Calculation of TSI values from data collected from a lake's epilimnion during summer stratification provide the best agreement between all of

the index parameters and facilitate comparisons between lakes. A TSI average value, calculated as the average of the three individually determined TSI values, is used by the District as an overall indicator of a reservoir's trophic state. The District uses the criteria defined in Table 4.1 for determining lake trophic status from TSI values.

Table 4.1. Lake trophic status based on calculated TSI values.

TSI	Trophic Condition
0-35	Oligotrophic
36-50	Mesotrophic
51-55	Moderately Eutrophic
56-65	Eutrophic
66-100	Hypereutrophic

4.1.4 IMPAIRMENT OF DESIGNATED WATER QUALITY-DEPENDENT BENEFICIAL USES

Water quality-dependent beneficial uses are designated to waterbodies in State water quality standards and criteria are defined to protect these uses. Water quality data collected by the District within the appropriate State define "age restrictions were assessed to determine if water quality conditions were impairing the designated beneficial uses. These data were assessed using the methodologies defined by the appropriate States in developing their 2010 Integrated Reports pursuant to the Federal Clean Water Act. It is noted that the "official" determination of whether water quality-dependent beneficial uses are impaired, pursuant to the Federal CWA, is by the States pursuant to their Section 305(b) and Section 303(d) assessments compiled in their biennial Integrated Water Quality Reports (See Table 1.3).

4.1.4.1 Assessment Methodologies Used for Nebraska Reservoirs

4.1.4.1.1 Assessment of Physicochemical Data

Nebraska water quality standards define acute and chronic numeric criteria for the protection of aquatic life and maximum criteria for the protection of public drinking and agricultural water supplies. Nebraska deems a designated use to be impaired if measured water quality conditions indicate that numeric criteria are exceeded more than 10 percent of the time over an assessed period (i.e., 5 years). To address the uncertainty associated with water quality data, the application of the 10 percent exceedence criterion is based on the number of measurements for the appropriate water quality criteria. Table 4.2 summarizes the Nebraska assessment measures regarding sample size and the number of exceedences that indicate an impaired use (i.e., 10% exceedence) at a 90% confidence level (i.e., α= 0.10).

Table 4.2. State of Nebraska Assessment Measures for Sample Size and Number of Exceedences Required to Determine an Impaired Use (i.e., 10% Exceedence).

Sample Size (n)	Number of Observations Exceeding a Criterion Required to Define an Impaired Use	Sample Size (n)	Number of Observations Exceeding a Criterion Required to Define an Impaired Use
<12	3	56 - 63	10
12 – 18	4	64 - 71	11
19 - 25	5	72 - 79	12
26 - 32	6	80 - 88	13
33 - 40	7	89 - 96	14
41 - 47	8	97 - 100	15
48 - 55	9	>100	Not Defined

4.1.4.1.2 Assessment of Fecal Coliform Bacteria, *E. Coli* Bacteria, and Cyanobacterial Toxins

Table 4.3 summarizes the Nebraska measures for the assessment of the Primary Contact Recreation Beneficial Use using fecal coliform bacteria, *E. coli* bacteria, and cyanobacterial toxin data.

Table 4.3. State of Nebraska measures for the assessment of the Primary Contact Recreation Beneficial Use using fecal coliform and *E. coli* bacteria data.

Parameter	Water Quality Criteria (Geometric Mean)	Supported	Impaired
Fecal Coliform	≤ 200cfu/100ml	Season geometric mean ≤ 200cfu/100ml	Season geometric mean > 200cfu/100ml
E. coli	≤ 126cfu/100ml	Season geometric mean ≤ 126cfu/100ml	Season geometric mean > 126cfu/100ml
Microcystin	--------------------	≤10% of samples exceed 20 ug/l	>10% of samples exceed 20 ug/l

4.1.4.1.3 Assessment of Reservoir Sedimentation

It is the State of Nebraska's position that excess sediment delivered to a lake can cause several problems including "objectionable colors, turbidity, and deposits." Deposition of sediment can displace or eliminate fish spawning and rearing and other aquatic habitats. Also, the recreation area of a lake can be reduced or rendered undesirable. Nebraska uses two measurements to assess lake sedimentation regarding the use of aesthetics: impoundment volume loss and sedimentation rate. Both the lake volume loss and sedimentation rate are based on the "as-built" conditions of the lake. Table 4.4 summarizes the Nebraska measures for the assessment of lakes regarding sedimentation.

Table 4.4. State of Nebraska measures for the assessment of lake sedimentation data.

Minimum Assessment Period	Supported	Impaired
≥5 Years	Volume loss < 25%, and Annual sedimentation rate ≤0.75%	Volume loss ≥ 25%, and Annual sedimentation rate >0.75%

4.1.4.1.4 Assessment of Reservoir Nutrient Data

Nebraska contends that excessive nutrient concentrations can promote adverse effects to water quality and biological populations within lakes. Some of these effects include reductions in dissolved oxygen, water clarity, biodiversity, and fish and wildlife habitat; and increases in bacteria concentrations, toxin mobility, ammonia toxicity, and in-lake filling. Nebraska uses the term "nutrients" to refer specifically to total nitrogen and total phosphorus. The presence of nitrogen and phosphorus do not directly impair uses; rather, the nutrients spur algal and other vegetative growth that causes use impairment from algal toxins, extreme diurnal pH fluctuations, and dissolved oxygen depletion. Table 4.5 summarizes the Nebraska measures for the assessment of lakes regarding nutrients.

Table 4.5. State of Nebraska measures for the assessment of lakes regarding nutrients.

Beneficial Use	Parameter	Assessment
Aquatic Life	Chlorophyll *a*	Growing Season Avg. > 10 ug/l
Aquatic Life	Total Nitrogen	Growing Season Avg. > 1000 ug/l
Aquatic Life	Total Phosphorus	Growing Season Avg. > 50 ug/l
Aquatic Life	pH	>10% of samples <6.5 or > 9.0
Aquatic Life	Dissolved Oxygen	>10% of samples exceed Aquatic Life Criteria

4.1.4.2 Assessment Methodologies Used for North Dakota Reservoirs

Sufficient and credible data requirements pertaining to the water quality monitoring data the District has collected at the Corps two tributary reservoirs in North Dakota include:

- Data collection and analysis followed known and documented quality assurance/quality control procedures.
- Water column data are 10 years old or less. Data for all 10 years of the period are not required to make an assessment.
- There should be a minimum of two samples collected from lakes or reservoirs during the growing season, May through September. The samples may consist of two samples collected in the same year or samples collected in separate years.

4.1.4.2.1 Assessment of Physicochemical Data

The following are the decision criteria that the State of North Dakota uses to determine if aquatic life use is impaired based on physicochemical data:

- For dissolved oxygen and pH, one or more standards were exceeded in more than 25 percent of the measurements taken during the previous 10 years. The temperature standard is exceeded in more than 10 percent of the measurements taken during the previous 10 years.

- For ammonia and other toxic pollutants (i.e., trace elements and organics), the acute or chronic standard was exceeded three or more times during any consecutive 3-year period during the past 10 years.

4.1.4.2.2 Assessment of Trophic Data

Trophic status is the primary indicator used to assess whether a lake is impaired. Under North Dakota protocols, it is assumed hypereutrophic lakes do not fully support a sustainable sport fishery and are limited in recreational uses, whereas mesotrophic lakes fully support both aquatic life and recreation use. Eutrophic lakes may be assessed as fully supporting, fully supporting but threatened, or not supporting their uses for aquatic life or recreation. North Dakota further assesses eutrophic lakes based on: 1) the lake's water quality standards fishery classification; 2) information provided by North Dakota Game and Fish Department Fisheries Division staff, local water resource managers, and the public; 3) the knowledge of land use in the lake's watershed; and/or 4) the relative degree of eutrophication. For example, a eutrophic lake, which has a well-balanced sport fishery and experiences infrequent algal blooms, is assessed as fully supporting with respect to aquatic life and recreation use. A eutrophic lake, which experiences periodic algal blooms and limited swimming use, would be assessed as not supporting recreation use. A lake fully supporting its aquatic life and/or recreation use, but for which monitoring has shown a decline in its trophic status (i.e., increasing phosphorus concentrations over time), would be assessed as fully supporting but threatened.

Carlson's Trophic State Index (TSI) is used to assess lake trophic status. When conducting an aquatic life and recreation use assessment for a lake, the average TSI score should be calculated for each indicator (i.e., chlorophyll *a*, Secchi depth, and total phosphorus). If TSI scores for each indicator result in a different trophic status assessment, the assessment should be based first on the chlorophyll *a*, followed by the Secchi depth transparency. Only when there are not adequate chlorophyll *a* and/or Secchi depth data available to make an assessment should total phosphorus concentration data be used.

4.1.4.3 <u>Assessment Methodologies Used for South Dakota Reservoirs</u>

Sufficient and credible data requirements pertaining to the water quality monitoring data the District has collected at the two Tributary Projects in South Dakota include:

- Data meets QA/QC requirements similar to those outlined in South Dakota Department of Environment and Natural Resources protocols.
- Data age (for both conventional and toxic parameters) for assessing existing water quality conditions of lakes should be from 2002 through 2010.
- For assessing lakes, 2 separate years of samples for conventional and Trophic State Index (TSI) parameters. Data must include at least one Secchi disk and chlorophyll *a* value. Samples dates must be between May 15 and September 15.

The following are the decision criteria that the State of South Dakota uses to determine if aquatic life use is impaired based on conventional water quality parameters:

- Required percentage of samples exceeding water quality standards in order to consider lake water quality impaired:
  - Greater than 10 percent of surface samples when 20 or more samples collected
  - Greater than 25 percent of surface samples if less than 20 samples collected.
- If one surface exceedence observed for water temperature, dissolved oxygen, or pH; lake profile data is used to make listing determinations. Lakes are considered fully supporting the aquatic life beneficial use if profile data indicate a region within the water column where temperature, pH, and dissolved oxygen meet numeric water quality standards. If a region does not exist the lake is considered impaired due to the parameter in exceedence.

4.2 WATER QUALITY TRENDS

Surface water quality trends were assessed by evaluating water clarity (i.e. Secchi depth), total phosphorus, chlorophyll *a*, and calculated average TSI values from monitoring results obtained at long-term, fixed-station ambient monitoring sites for the period 1980 to 2010.

5 COLORADO TRIBUTARY PROJECTS

Three District Tributary Projects are located in north-central Colorado: Bear Creek, Chatfield, and Cherry Creek (Figure 1.1). The three projects are commonly referred to as the Colorado Tri-Lakes Project. All three project reservoirs are located in the Denver, Colorado metropolitan area (Figure 5.1). Table 5.1 gives selected engineering data for the Colorado Tri-Lakes Tributary Projects.

5.1 BEAR CREEK RESERVOIR

5.1.1 BACKGROUND INFORMATION

5.1.1.1 Project Overview

The dam forming Bear Creek Reservoir is located on Bear Creek, 3 miles southwest of Denver, Colorado (Figure 5.1). The dam was completed in July 1977 and the reservoir reached its initial fill in May 1979. The Bear Creek Reservoir watershed is 236 square miles. The watershed was rangeland, forested, and residential/acreage development when the dam was built in 1974. Urbanization of the watershed is occurring with the growth of the Denver metropolitan area. The authorized project purposes for Bear Creek Reservoir are: flood control, recreation, and fish and wildlife. An upgraded aeration system was installed in Bear Creek Reservoir in 2002 to improve water quality.

5.1.1.2 Bear Creek Dam Intake Structure

The outlet works at Bear Creek Dam consist of a reinforced concrete intake structure with high-level drop inlets and a low-level 36-inch diameter reinforced concrete pipe and intake upstream of the intake structure. The gate structure is contained in the dam just upstream of the impervious core. The high-level drop inlets have two weirs at elevation 5558.0 ft-msl (multipurpose pool level). Two lower-level gated inlets are located at invert elevations of 5538.0 and 5528.0 ft-msl. The low-level intake at elevation 5528.0 ft-msl is 135 feet upstream from the main intake structure.

5.1.1.3 Reservoir Storage Zones

Figure 5.2 depicts the current storage zones of Bear Creek Reservoir based on the 2009 survey data and estimated sedimentation. It is estimated that 7 percent of the Multipurpose Pool has been lost to sedimentation as of 2010.

5.1.1.4 Water Quality Standards Classifications, Section 303(d) Listings, and Fish Consumption Advisories

The State of Colorado's water quality standards designate the following beneficial uses to Bear Creek Reservoir: primary contact recreation, domestic water supply, Class 1 coldwater aquatic life, and agriculture. Pursuant to Section 303(d) of the CWA, the State of Colorado has placed Bear Creek Reservoir on the State's 303(d) monitoring and evaluation list (Table 1.3). Bear Creek Reservoir is listed for impairment to aquatic life due to elevated chlorophyll *a* levels resulting from high phosphorus loadings to the reservoir. Bear Creek Reservoir remains on the State of Colorado's monitoring and evaluation list for dissolved oxygen.

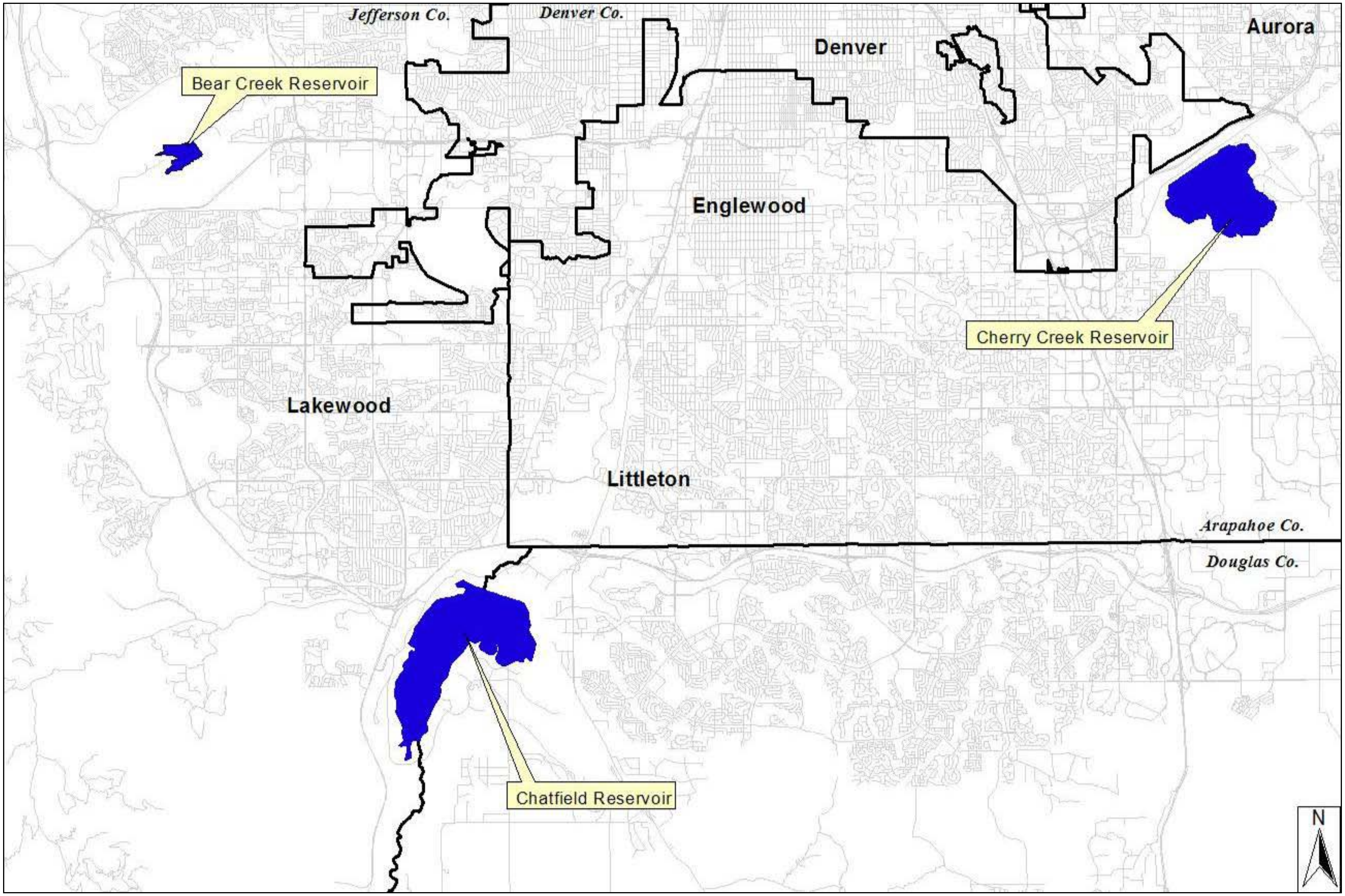

Figure 5.1. Locations of Bear Creek, Chatfield, and Cherry Creek Reservoirs in the Denver, Colorado metropolitan area.

Table 5.1. Summary of selected engineering data for the Colorado Tri-Lakes Tributary Projects.

	Beak Creek Reservoir	**Chatfield Reservoir**	**Cherry Creek Reservoir**
General			
Dammed Stream	Bear Creek	South Platte River	Cherry Creek
Drainage Area	236 sq. mi.	3,018 sq. mi.	386 sq. mi.
Reservoir Length[1]	0.5 miles	2.0 miles	1.5 miles
Multipurpose Pool Elevation (Top)	5558.0 ft-msl	5,432.0 ft-msl	5550.0 ft-msl
Date of Dam Closure	July 1977	August 1973	October 1948
Date of Initial Fill[2]	May 1979	June 1979	March 1960
"As-Built" Conditions[3]	(1980 Survey Data)	(1977 Survey Data)	(1950 Survey Data)
Lowest Reservoir Bottom Elevation	5522 ft-msl	5379 ft-msl	5504 ft-msl
Surface Area at top of Multipurpose Pool	109 ac	1,444 ac	886 ac
Capacity of Multipurpose Pool	1,964 ac-ft	28,076 ac-ft	15,155 ac-ft
Mean Depth at top of Multipurpose Pool[4]	18.0 ft	19.4 ft	17.1 ft
Latest Surveyed Conditions	(2009 Survey Data)	(2010 Survey Data)	1988
Lowest Reservoir Bottom Elevation	5520 ft-msl	5382 ft-msl	5523 ft-msl
Surface Area at top of Multipurpose Pool	107 ac	1,412 ac	847 ac
Capacity of Multipurpose Pool	1,824 ac-ft	27,076 ac-ft	12,805 ac-ft
Mean Depth at top of Multipurpose Pool[4]	17.0 ft	19.2 ft	15.1 ft
Sediment Deposition in Multipurpose Pool			
Historic Sediment Deposition[5]	140 ac-ft	1000 ac-ft	2,350 ac-ft
Annual Sedimentation Rate[6]	1980-2009 4.8 ac-ft/yr	1977-2010 30.3 ac-ft/yr	1950-1988 60.3 ac-ft/yr
Current Estimated Sediment Deposition[7]	144 ac-ft	1000 ac-ft	3,618 ac-ft
Current capacity of Multipurpose Pool[8]	1,820 ac-ft	27,076 ac-ft	11,537 ac-ft
Percent of "As-Built" Multipurpose Pool capacity lost to current estimated sediment deposition	7%	4%	24%
Operational Details – Historic	(1980 – 2010)	(1980 – 2010)	(1958 – 2010)
Maximum Recorded Pool Elevation	5587.1 ft-msl 18-Jun-95	5447.6 ft-msl 26-May-80	5565.8 ft-msl 3-Jun-73
Minimum Recorded Pool Elevation	5521.7 ft-msl 19-Jul-78	5399.4 ft-msl 6-Jun-76	5512.5 ft-msl 15-May-58
Maximum Recorded Daily Inflow	910 cfs 1-May-80	3,394 cfs 2-Jul-95	6,150 cfs 16-Jun-65
Maximum Recorded Daily Outflow	800 cfs 5-May-80	3,350 cfs 7-Jul-95	560 cfs 7-Aug-65
Average Annual Pool Elevation	5556.5 ft-msl	5428.3 ft-msl	5548.9 ft-msl
Average Annual Inflow	33,272 ac-ft	154,594 ac-ft	11,285 ac-ft
Average Annual Outflow	32,904 ac-ft	142,935 ac-ft	8,442 ac-ft
Estimated Retention Time[10]	0.06 Years	0.19 Years	1.37 Years
Operational Details – Current[11]			
Maximum Recorded Pool Elevation	5560.0 ft-msl 24-Apr-10	5433.6 ft-msl 25-Apr-10	5552.0 ft-msl 25-Apr-10
Minimum Recorded Pool Elevation	5557.8 ft-msl 30-Mar-10	5427.0 ft-msl 11-Aug-10	5549.0 ft-msl 29-Sep-10
Maximum Recorded Daily Inflow	260 cfs 23-Apr-10	1099 cfs 15-Jun-10	514 cfs 24-Apr-10
Maximum Recorded Daily Outflow	251 cfs 24-Apr-10	1428 cfs 28-Apr-10	323 cfs 28-Apr-10
Total Inflow (% of Average)	35,219 ac-ft (101%)	127,031 ac-ft (84%)	26,803 ac-ft (236%)
Total Outflow (% of Average)	34,946 ac-ft (102%)	128,696 ac-ft (87%)	25,327 ac-ft (299%)
Outlet Works			
Ungated Outlets	Drop Inlet 5558.0 ft-msl		2) 1.0'x2.5' 5504.0 ft-msl 2) 2.0'x6.0' 5509.0 ft-msl
Gated Outlets (Mid-depth)	2) 3' x 6' hydraulic slide 1) 36" Dia. 5538.0 ft-msl	2) 6' x 13.5' hydraulic slide 2) 2' x 2' slide gate on gate 1) 6' butterfly	5) 6' x 9' hydraulic slide
Gated Outlets (Low-level)	1) 36" Dia. 5528.0 ft-msl	none	2) 18" by-pass gates

(1) Reservoir length at top of conservation pool.
(2) First occurrence of reservoir pool elevation to top of multipurpose pool elevation.
(3) "As-Built" conditions taken to be the conditions present when the reservoir was first surveyed.
(4) Mean Depth = Volume ÷ Surface Area.
(5) Difference in reservoir storage capacity to top of Multipurpose Pool between "as-built" and latest survey.
(6) Annualized rate based on historic accumulated sediment.
(7) Current accumulated sediment estimated from historic annual sedimentation rate.
(8) Current capacity of Multipurpose Pool = "As-Built" Multipurpose Pool capacity - Estimated Current Sedimentation.
(9) Reservoir drawn down for lake restoration project.
(10) Estimated Retention Time = Multipurpose Pool Volume ÷ Average Annual Outflow.
(11) Current operational details are for the water year 1-Oct-2009 through 30-Sep-2010.

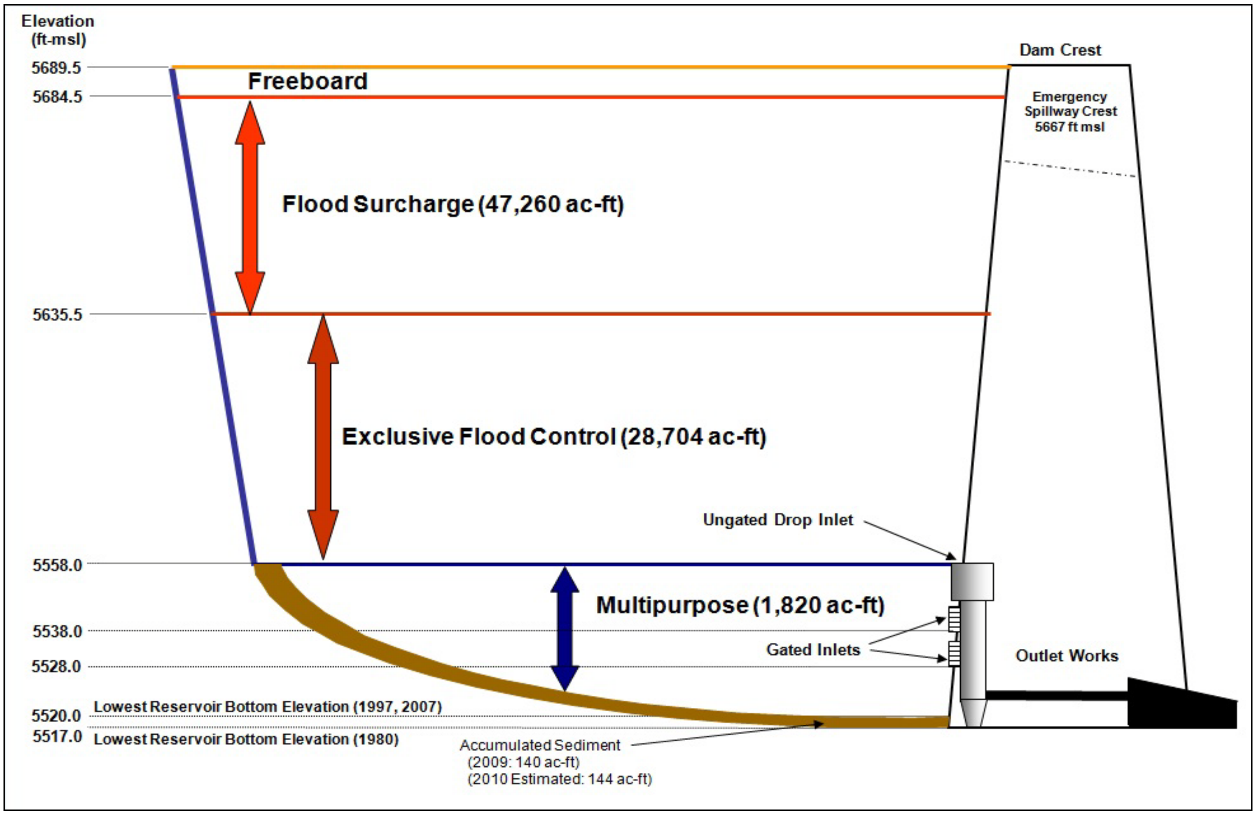

Figure 5.2. Current storage zones of Bear Creek Reservoir based on the 2009 survey data and estimated sedimentation.

5.1.1.5 <u>Ambient Water Quality Monitoring</u>

A Local Watershed Authority has been established for Bear Creek Reservoir to protect and improve water quality at the reservoir. The Bear Creek Watershed Authority has adopted local water quality regulations and a water quality management plan to protect and manage water quality in Bear Creek Reservoir. As part of its water quality management plan, the Bear Creek Watershed Authority is implementing a comprehensive water quality monitoring program. For efficiency purposes, the District ceased its water quality monitoring activities at Bear Creek Reservoir in 2002, and now defers to the Bear Creek Watershed Authority for assessment of water quality conditions at Bear Creek Reservoir. Prior to 2002, the District had monitored water quality at Bear Creek Reservoir since the 1970's.

5.1.2 EXISTING WATER QUALITY CONDITIONS

Persons interested in existing water quality conditions at Bear Creek Reservoir can visit the website maintained by the Bear Creek Watershed Association (http://www.bearcreekwatershed.org).

5.2 CHATFIELD RESERVOIR

5.2.1 BACKGROUND INFORMATION

5.2.1.1 <u>Project Overview</u>

The dam forming Chatfield Reservoir is located on the South Platte River, 2 miles south of Denver, Colorado (Figure 5.1). The dam was completed in August 1973 and the reservoir reached its initial fill in June 1979. The Chatfield Reservoir watershed is 3,018 square miles. The watershed was

rangeland, forested, and residential/acreage development when the dam was built in 1973. Urbanization of the watershed is occurring with the growth of the Denver metropolitan area. The authorized project purposes for Chatfield Reservoir are: flood control, recreation, fish and wildlife, and water supply.

5.2.1.2 Chatfield Dam Intake Structure

The intake structure has three gated passageways which conduct water to a twin conduit. The two right passageways have a service and emergency gate which are controlled by hydraulic hoists. In each gate a 2-foot x 2-foot auxiliary gate is provided to facilitate regulation of normal flows to the river. In the left passageway of the intake structure a 6-foot diameter penstock, equipped with a butterfly valve near the upstream end, is provided to conduct releases to satisfy the downstream water rights.

5.2.1.3 Reservoir Storage Zones

Figure 5.3 depicts the current storage zones of Chatfield Reservoir based on the 2010 survey data and estimated sedimentation. It is estimated that 4 percent of the Multipurpose Pool has been lost to sedimentation as of 2010.

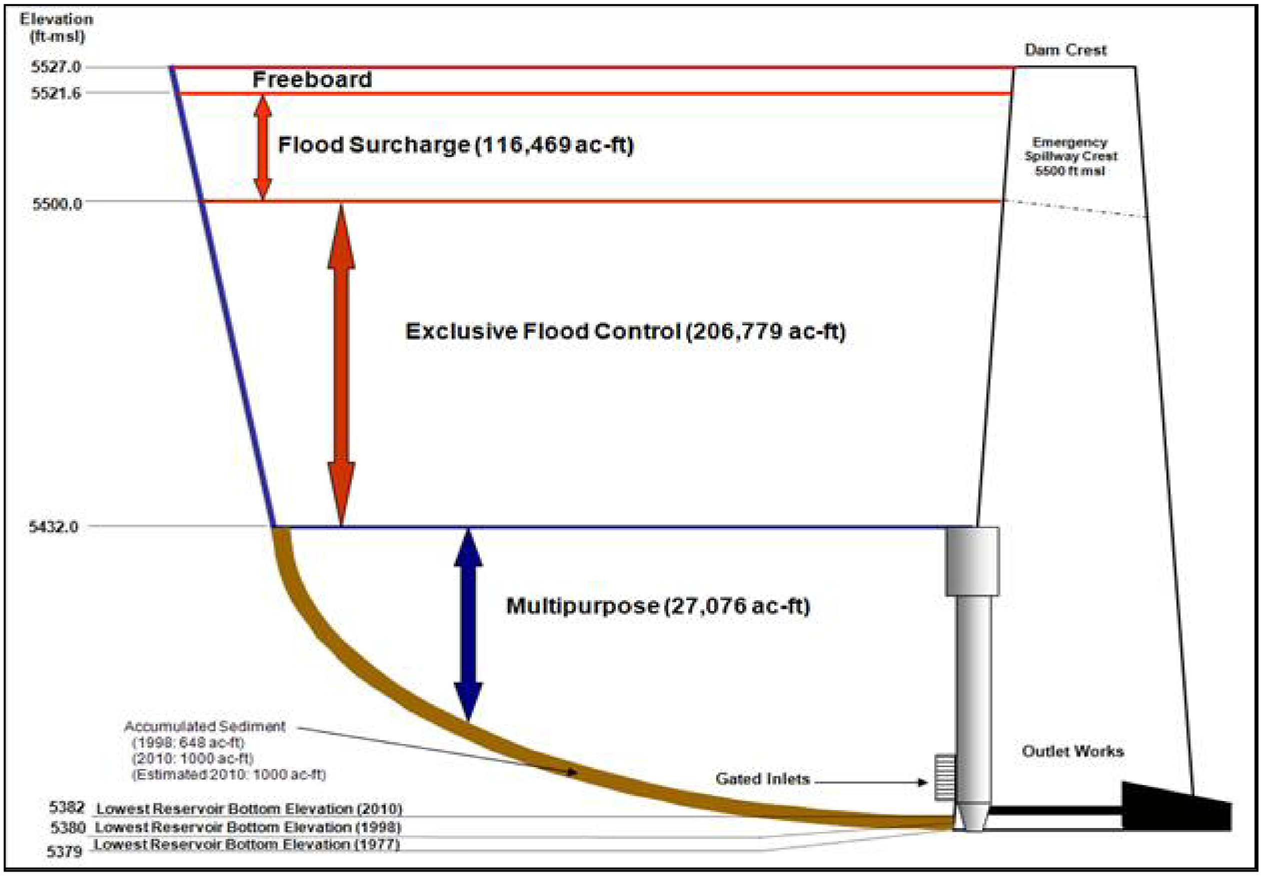

Figure 5.3. Current storage zones of Chatfield Reservoir based on the 2010 survey data and estimated sedimentation.

5.2.1.4 Water Quality Standards Classifications, Section 303(d) Listings, and Fish Consumption Advisories

The State of Colorado's water quality standards designate the following beneficial uses to Chatfield Reservoir: primary contact recreation, domestic water supply, Class 1 coldwater aquatic life, and agriculture. Chatfield Reservoir is a source of public drinking water for the Cities of Denver, Englewood, and Littleton, Colorado. Pursuant to Section 303(d) of the CWA, the State of Colorado has not placed Chatfield Reservoir on the State's 303(d) list of impaired waters. The State of Colorado has not issued a fish consumption advisory for Chatfield Reservoir.

5.2.1.5 Ambient Water Quality Monitoring

A Local Watershed Authority has been established for Chatfield Reservoir to protect and improve water quality at the reservoir. The Chatfield Watershed Authority has adopted local water quality regulations and a water quality management plan to protect and manage water quality in Chatfield Reservoir. As part of its water quality management plan, the Chatfield Watershed Authority is implementing a comprehensive water quality monitoring program. For efficiency purposes, the District ceased its water quality monitoring activities at Chatfield Reservoir in 2002, and now defers to the Chatfield Watershed Authority for assessment of water quality conditions at Chatfield Reservoir. Prior to 2002, the District had monitored water quality at Chatfield Reservoir since the 1970's.

5.2.2 EXISTING WATER QUALITY CONDITIONS

Persons interested in existing water quality conditions at Chatfield Reservoir can visit the website maintained by the Chatfield Watershed Association (http://www.chatfieldwatershedauthority.org).

5.3 CHERRY CREEK RESERVOIR

5.3.1 BACKGROUND INFORMATION

5.3.1.1 Project Overview

The dam forming Cherry Creek Reservoir is located on Cherry Creek, southeast of Denver, Colorado (Figure 5.1). The dam was completed in October 1948 and the reservoir reached its initial fill in March 1960. The Cherry Creek Reservoir watershed is 386 square miles. The watershed was rangeland and agricultural when the dam was built in 1948. Extensive urbanization of the watershed has occurred with the growth of the Denver metropolitan area. The authorized project purposes for Cherry Creek Reservoir are: flood control, recreation, and fish and wildlife. An aeration system to de-stratify the reservoir to improve water quality was installed in 2007 and became operational on April 4, 2008.

5.3.1.2 Cherry Creek Dam Intake Structure

The Cherry Creek Dam intake tower contains five rectangular water passages with a 6' x 9' slide gate in each to control water flow. Two emergency gates have also been added to the intake structure. These gates can be installed while water is flowing thru a water passage, but are not to be used for regulating flow. A low-flow by-pass was installed in February 1988 to allow finer regulation of flow to downstream water rights users. The low-flow by-pass consists of two 18" knife valves.

5.3.1.3 Reservoir Storage Zones

Figure 5.4 depicts the current storage zones of Cherry Creek Reservoir based on the 1988 survey data and estimated sedimentation. It is estimated that 24 percent of the Multipurpose Pool has been lost to sedimentation as of 2010. A sediment survey was conducted at Cherry Creek Reservoir in 2008, but final results were not available at the time of this report.

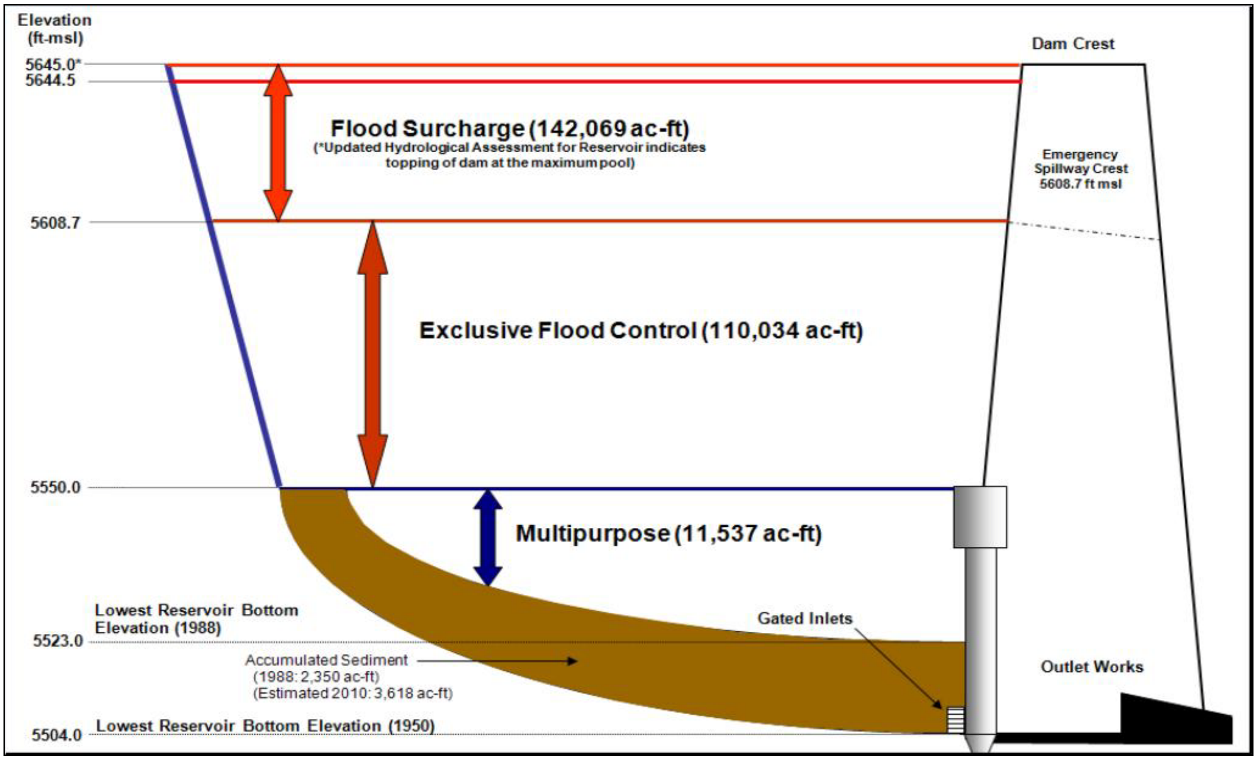

Figure 5.4. Current storage zones of Cherry Creek Reservoir based on the 1988 survey data and estimated sedimentation.

5.3.1.4 Water Quality Standards Classifications, Section 303(d) Listings, and Fish Consumption Advisories

The State of Colorado's water quality standards designate the following beneficial uses to Cherry Creek Reservoir: primary contact recreation, domestic water supply, Class 1 warmwater aquatic life, and agriculture. In 2010 Cherry Creek Reservoir was removed from the State of Colorado's 303(d) list of impaired waters. Cherry Creek Reservoir had been listed in 2008 for impairment to the uses of aquatic life and primary contact recreation due to elevated chlorophyll *a* levels resulting from high phosphorus loadings to the reservoir. Cherry Creek Reservoir remains on the State of Colorado's monitoring and evaluation list for dissolved oxygen (Table 1.3). The State of Colorado has not issued a fish consumption advisory for Cherry Creek Reservoir.

5.3.1.5 Ambient Water Quality Monitoring

A Local Watershed Authority has been established for Cherry Creek Reservoir to protect and improve water quality at the reservoir. The Cherry Creek Basin Watershed Authority has adopted local

water quality regulations and a water quality management plan to protect and manage water quality in Cherry Creek Reservoir. As part of its water quality management plan, the Cherry Creek Basin Watershed Authority is implementing a comprehensive water quality monitoring program. For efficiency purposes, the District ceased its water quality monitoring activities at Cherry Creek Reservoir in 2002, and now defers to the Cherry Creek Basin Watershed Authority for assessment of water quality conditions at Cherry Creek Reservoir. Prior to 2002, the District had monitored water quality at Cherry Reservoir since the 1970's.

5.3.2 EXISTING WATER QUALITY CONDITIONS

Persons interested in existing water quality conditions at Cherry Creek Reservoir can visit the website maintained by the Cherry Creek Basin Watershed Authority (http://www.cherrycreekbasin.org).

6 NEBRASKA TRIBUTARY PROJECTS

Tributary projects in Nebraska occur in two primary watersheds in the southeast area of the State: Papillion Creek in the Omaha area and Salt Creek in the Lincoln area (Figure 1.1).

6.1 PAPILLION CREEK TRIBUTARY PROJECTS

6.1.1 BACKGROUND INFORMATION

6.1.1.1 Papillion Creek Watershed Hydrology

Streamflow in the Papillion Creek watershed follows a characteristic pattern. Flows are generally low except for brief periods of rise caused by runoff from rainfall events. A snowpack over the basin in early spring can produce a significant rise in flow as a result of snowmelt runoff. During the winter months streams in the basin are generally frozen over.

6.1.1.2 Tributary Reservoirs

Four District tributary reservoirs (i.e., Ed Zorinsky, Glenn Cunningham, Standing Bear, and Wehrspann) are located in the Papillion Creek watershed in the vicinity of Omaha, Nebraska (Figure 6.1). The authorized purposes for the four reservoirs are flood control, recreation, fish and wildlife, and water quality. Table 6.1 gives selected engineering data for each of the four reservoirs. A low-level outlet is installed at each dam to permit draining of the multipurpose pools in approximately a 1-month time period. This outlet may also be used to hasten the evacuation of flood storage so as to avoid damage to shoreline grasses and recreational facilities. The low-level outlet may also be used for water quality management purposes by providing: 1) downstream flow augmentation releases during low-flow periods, and 2) targeted withdrawal from the bottom of the reservoir.

6.1.1.2.1 Water Quality Standards Classifications and Section 303(d) Listings

The State of Nebraska's water quality standards designates the following beneficial uses to all the Papillion Creek tributary project reservoirs: recreation, warmwater aquatic life, agricultural water supply, and aesthetics. None of the reservoirs are used as a public drinking water supply or have designated swimming beaches. The State's water quality standards also identify nutrient criteria for lakes and impounded waters based on the categorization of the physical, chemical, and biological characteristics of the waterbody. Under this categorization, Ed Zorinsky, Standing Bear, and Wehrspann Reservoirs have been included in a common group categorized as R13 impounded waters. Glenn Cunningham Reservoir is included in another grouping categorized as R14 impounded waters.

Pursuant to the Federal CWA, the State of Nebraska has listed all the Papillion Creek Tributary project reservoirs on the State's 2010 Section 303(d) list (see Table 1.3). The beneficial use of aquatic life is identified as impaired in all four reservoirs, and aesthetics is identified as impaired in Standing Bear Reservoir. The identified pollutants/stressors include: dissolved oxygen, chlorophyll a, and nutrients (Glenn Cunningham Reservoir) and mercury (Ed Zorinsky, Standing Bear, and Wehrspann Reservoirs). The State of Nebraska has issued fish consumption advisories for Ed Zorinsky, Standing Bear, and Wehrspann Reservoirs due to mercury concerns. TMDLs have been completed for Ed Zorinsky and Standing Bear Reservoirs.

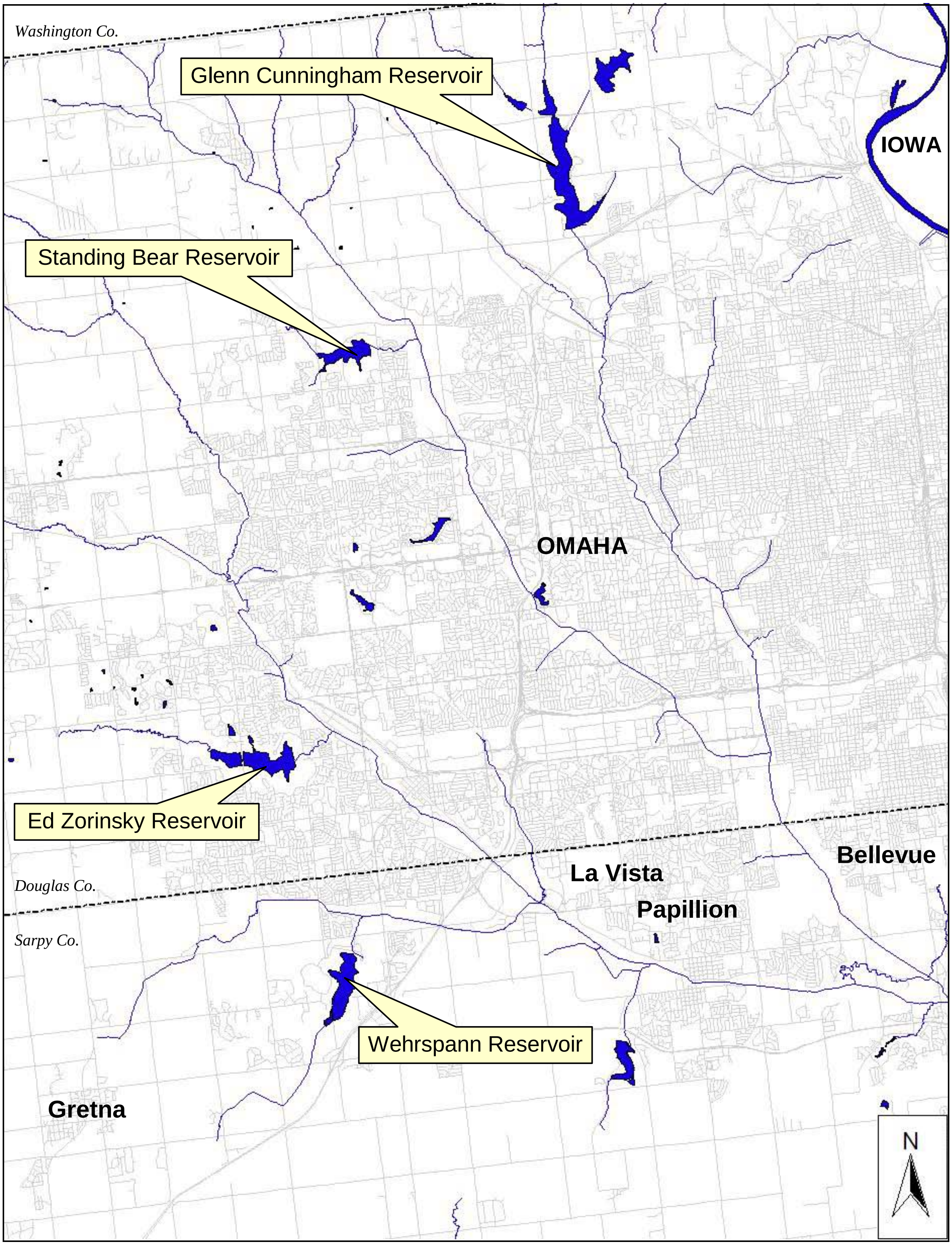

Figure 6.1. Locations of the Corps tributary project reservoirs in the Omaha, Nebraska area.

Table 6.1. Summary of selected engineering data for the Papillion Creek tributary projects.

	Ed Zorinsky Reservoir (Dam Site No. 18)		**Glenn Cunningham Reservoir (Dam Site No. 11)**		**Standing Bear Reservoir (Dam Site No. 16)**		**Wehrspann Reservoir (Dam Site No. 20)**	
General								
Dammed Stream	Boxelder Creek		Knight Creek		Trib. Big Papillion Ck		Trib. So Br Papillion Ck	
Drainage Area	16.4 sq. mi.		17.8 sq. mi.		6.0 sq. mi.		13.1 sq. mi.	
Reservoir Length[1]	1.5 miles		2.5 miles		1.0 miles		1.5 miles	
Designated Water Quality Storage	620 ac-ft		820 ac-ft		0 ac-ft		490 ac-ft	
Multipurpose Pool Elevation (Top)	1110.0 ft-msl		1121.0 ft-msl		1104.0 ft-msl		1095.8 ft-msl	
Date of Dam Closure	7 Dec 1989[2]		5 Aug 1974		3 Oct 1972		21 Sep 1982	
Date of Initial Fill[3]	22 Apr 1992		2 Sep 1977		24 Oct 1977		26 May 1987	
"As-Built" Conditions[4]	(1985)		(1976)		(1976)		(1984)	
Lowest Reservoir Bottom Elevation	1074 ft-msl		1090 ft-msl		1073 ft-msl		1060 ft-msl	
Surface Area at top of Multipurpose Pool	259 ac		395 ac		135 ac		239 ac	
Capacity of Multipurpose Pool	3,037 ac-ft		3,705 ac-ft		1,504 ac-ft		2,640 ac-ft	
Mean Depth at top of Multipurpose Pool[5]	11.7 ft		9.4 ft		11.1 ft		11.0 ft	
Surveyed Conditions	(2007:USACE)	(2002:USGS)	(2009:USACE)	(2001:NGPC)	(2009:USACE)	(2005:USGS)	(2009:USACE)	(2002:NCPC)
Lowest Reservoir Bottom Elevation	1080 ft-msl	1077 ft-msl	1101 ft-msl	1100 ft-msl	1086 ft-msl	1082 ft-msl	1070 ft-msl	1068 ft-msl
Surface Area at top of Multipurpose Pool	247 ac	246 ac	337 ac	348 ac	123 ac	116 ac	236 ac	227 ac
Capacity of Multipurpose Pool	2,781 ac-ft	2,870 ac-ft	3,015 ac-ft	2,879 ac-ft	1,141 ac-ft	1,278 ac-ft	2,302 ac-ft	2,274 ac-ft
Mean Depth at top of Multipurpose Pool[5]	11.3 ft	11.7 ft	8.9 ft	8.3 ft	9.3 ft	11.0 ft	9.8 ft	10.0 ft
Sediment Deposition in Multipurpose Pool	(2007:USACE)	(2002:USGS)	(2009:USACE)	(2001:NGPC)	(2009:USACE)	(2005:USGS)	(2009:USACE)	(2002:NCPC)
Surveyed Sediment Deposition[6]	256 ac-ft	167 ac-ft	690 ac-ft	826 ac-ft	363 ac-ft	226 ac-ft	338 ac-ft	366 ac-ft
Annual Sedimentation Rate[7]	11.6 ac-ft/yr	9.3 ac-ft	20.9 ac-ft/yr	31.8 ac-ft/yr	11 ac-ft/yr	7.5 ac-ft/yr	15.4 ac-ft/yr[11]	19.3 ac-ft/yr[11]
Current Estimated Sediment Deposition[8]	290 ac-ft	242 ac-ft	711 ac-ft	742 ac-ft[10]	374 ac-ft	249 ac-ft	353 ac-ft	460 ac-ft
Current capacity of Multipurpose Pool[9]	2,747 ac-ft	2,795 ac-ft	2994 ac-ft	2,963 ac-ft[10]	1,130 ac-ft	1,255 ac-ft	2,287 ac-ft	2,180 ac-ft
Percent of "As-Built" Multipurpose Pool capacity lost to current estimated sediment deposition	10%	8%	19%	20%[10]	25%	18%	13%	17%
Operational Details – Historic	(1991 – 2010)		(1978 – 2010)		(1978 –2010)		(1987 – 2010)	
Maximum Recorded Pool Elevation	1116.8 ft-msl	24-Jul-93	1125.3 ft-msl	7-Aug-99	1108.6 ft-msl	12-Jun-08	1103.2 ft-msl	24-Jul-93
Minimum Recorded Pool Elevation	1102.4 ft-msl	1-Jun-92	1100.9 ft-msl[12]	2006-2008	1087.5 ft-msl	1-Nov-73	1077.4 ft-msl	1-Mar-86
Maximum Recorded Daily Inflow	561 cfs	14-Jun-91	931 cfs	7-Aug-99	266 cfs	14-Jun-84	678 cfs	28-Jun-93
Maximum Recorded Daily Outflow	142 cfs	25-Jul-93	157 cfs	8-Aug-99	65 cfs	16-Jun-84	124 cfs	25-Jul-93
Average Annual Pool Elevation	1109.4 ft-msl		1119.4 ft-msl		1102.2 ft-msl		1092.8 ft-msl	
Average Annual Inflow	4,852 ac-ft		6,734 ac-ft		1,585 ac-ft		2,332 ac-ft	
Average Annual Outflow	4,151 ac-ft		5,549 ac-ft		1,126 ac-ft		1,309 ac-ft	
Estimated Retention Time[13]	0.66 Years		0.54 Years		1.00 Years		1.75 Years	
Operational Details – Current[14]								
Maximum Recorded Pool Elevation	1112.9 ft-msl	23-Jun-10	1123.6 ft-msl	14-Jun-10	1105.8	11-Jul-10	1098.9	23-Jun-10
Minimum Recorded Pool Elevation	1110.1 ft-msl	4-Oct-09	1121.2 ft-msl	01-Oct-09	1103.5	07-Sep-10	1095.5	20-Oct-09
Maximum Recorded Daily Inflow	288 cfs	21-Jun-10	209 cfs	5-Jun-10	114 cfs	11- Jul-10	179 cfs	23-Jun-10
Maximum Recorded Daily Outflow	84 cfs	23-Jun-10	102 cfs	15-Jun-10	53cfs	27-Sep-10	74 cfs	24-Jun-10
Total Inflow (% of Average Annual)	10,280 ac-ft	(203%)	11,564 ac-ft	(169%)	4330 ac-ft	(284%)	6242 ac-ft	(262%)
Total Outflow (% of Average Annual)	9,389 ac-ft	(221%)	10,479 ac-ft	(186%)	3889 ac-ft	(366%)	4,854 ac-ft	(361%)
Outlet Works								
Ungated Outlets	2) 1.5'x3.5' 2) 3.2'x8.0'	1110.0 ft-msl 1117.6 ft-msl	2) 2.0'x4.0' 2) 2.5'x9.0'	1121.0 ft-msl 1127.5 ft-msl	2) 1.0'x2.5' 2) 2.0'x6.0'	1104.0 ft-msl 1109.0 ft-msl	2) 1.3'x3.5' 2) 3.7'x8.0'	1095.8 ft-msl 1103.4 ft-msl
Gated Outlets (Mid-depth)	1) 6" Dia.	1104.3 ft-msl	None		None		1) 6" Dia.	1090.0 ft-msl
Gated Outlets (Low-level)	1) 30"x30"	1090.0 ft-msl	1) 30"x30"	1100.0 ft-msl	1) 24"x36"	1080.0 ft-msl	1) 30"x30"	1077.0 ft-msl

Note: All elevations given are in the NGVD 29 datum.

(1) Reservoir length at top of multipurpose pool.
(2) Dam completed 15-Jul-1984, low-level gate closed 7-Dec-1989.
(3) First occurrence of reservoir pool elevation to top of multipurpose pool elevation.
(4) "As-Built" conditions taken to be the conditions present when the reservoir was first surveyed.
(5) Mean Depth = Volume ÷ Surface Area.
(6) Surveyed sediment deposition is the difference in reservoir storage capacity to top of Multipurpose Pool between "as-built" and survey.
(7) Annualized rate based on historic accumulated sediment.
(8) Current accumulated sediment estimated from historic annual sedimentation rate.
(9) Current capacity of Multipurpose Pool = "As-Built" Multipurpose Pool capacity - Estimated Current Sedimentation.
(10) A lake restoration project was finished in 2008 that included dredging and removal of 275 ac-ft of sediment.
(11) Estimated rate before completion of restoration project in 1999. Estimated rate after 1999 is ½ of this rate.
(12) Reservoir drawn down for lake restoration project.
(13) Estimated Retention Time = Current Estimated Multipurpose Pool Volume ÷ Average Annual Outflow.
(14) Current operational details are for the water year 1-Oct-2009 through 30-Sep-2010.

6.1.1.2.2 Reservoir Regulation for Water Quality Management

6.1.1.2.2.1 Downstream Water Quality Management

When the Papillion Creek Tributary projects were authorized water quality management was identified as a concern within the Papillion Creek basin. At that time, studies by the Federal Water Pollution Control Administration (FWPCA) indicated that a need existed for water quality storage within the basin. The FWPCA identified the need for 3 cfs water quality flow in the Big Papillion Creek, Little Papillion Creek, and West Branch Papillion Creek. The FWPCA's studies indicated 8 of the proposed 21 reservoirs would collectively have sufficient storage to provide the identified 3 cfs water quality flows. Based on the costs of an alternative groundwater pumping project at that time, the storage was estimated to have an annual value of $10,700. Dam sites 11 (i.e., Glenn Cunningham), 18 (i.e., Ed Zorinsky), and 20 (i.e., Wehrspann) were included in the eight reservoirs potentially identified for having a water quality component in the multipurpose pool. Originally, Dam site 11 was to have a multipurpose pool of 4,600 ac-ft, of which 820 ac-ft was indicated as the water quality storage component. The 1976 survey of Glenn Cunningham Reservoir determined the multipurpose storage of the reservoir at that time was 3,705 ac-ft. Originally, Dam site 18 was to have a multipurpose pool of 4,700 ac-ft with a water quality component of 620 ac-ft. The 1984 survey of Ed Zorinsky Reservoir established the "as-built" multipurpose storage of the reservoir at 3,037 ac-ft. Originally, Dam site 20 was to have a multipurpose storage of 3,700 ac-ft with a water quality storage component 490 ac-ft. The 1984 survey of Wehrspann Reservoir determined the multipurpose storage of the reservoir at that time was 2,640 ac-ft. The multipurpose pools at the four Papillion Creek reservoirs were projected to fill with sediment in 100 years. To date, releases for downstream water quality management have not been necessary because seepage, releases, and/or tributary inflows at Dam sites 11, 18, and 20 have provided adequate flow for water quality purposes.

6.1.1.2.2.2 Reservoir Water Quality Management

Since authorized water quality storage has not been required for downstream water quality management, it is available for reservoir water quality management. The Papillion Creek tributary reservoirs are dimictic to polymixic and near-bottom areas of the reservoirs become anoxic during the summer and winter. Releases could be made from the reservoirs through the low-level outlet to discharge poor quality water during these times and replace it with better quality inflow water. Such releases could also promote mixing within the reservoirs and possibly improve dissolved oxygen conditions in lower depths when the reservoirs are thermally stratified.

6.1.2 ED ZORINSKY RESERVOIR

6.1.2.1 <u>Background Information</u>

6.1.2.1.1 Project Overview

The dam forming Ed Zorinsky Reservoir is located on Boxelder Creek, a tributary of the South Papillion Creek in the West Branch Papillion Creek basin. The Ed Zorinsky Reservoir watershed is 16.4 square miles. The watershed was largely agricultural when the dam was built in 1984; however since then, the watershed has undergone extensive urbanization with the growth of Omaha.

The dam was completed on July 20, 1984; however, potential water quality problems delayed closure. Two wastewater treatment facilities occasionally discharged to upstream tributaries of the reservoir and it was decided to delay final closure until the situation was addressed. The situation was corrected by constructing a diversion pipeline to the Elkhorn River in the fall of 1989. The low-level gate at the dam was closed on December 7, 1989 and the reservoir reached its initial fill in April 1992.

6.1.2.1.2 Ed Zorinsky Dam Intake Structure

The reinforced concrete intake structure at Ed Zorinsky Dam has four upper-level intakes (two at invert elevation 1110.0 ft-msl and two at invert elevation 1117.6 ft-msl), an intermediate-level intake (invert elevation 1104.3 ft-msl), and a low-level intake (invert elevation 1090 ft-msl). The upper-level intakes are uncontrolled. The intermediate-level intake has a 6-inch diameter slide gate for flow augmentation releases for water quality management. The low-level intake is provided with a slide gate to permit draining of the reservoir below elevation 1110.0 ft-msl in the event drawdown is desirable. The low-level inlet is constructed 240 feet upstream of the intake tower. The inlet is provided with a trash rack and emergency bulkhead to allow closure with the gate open. A 30-inch reinforced concrete pipe connects the low-level inlet to the intake structure.

6.1.2.1.3 Reservoir Storage Zones

Figure 6.2 depicts the current storage zones of Ed Zorinsky Reservoir based on the 2007 Corps survey data and estimated sedimentation. It is estimated that 8 to 10 percent of the "as-built" Multipurpose Pool has been lost to sedimentation as of 2010 with the annual volume loss estimated to be 0.38 percent. Based on the State of Nebraska's impairment assessment methodology, these values indicate that Ed Zorinsky Reservoir's water quality dependent uses are not impaired due to sedimentation.

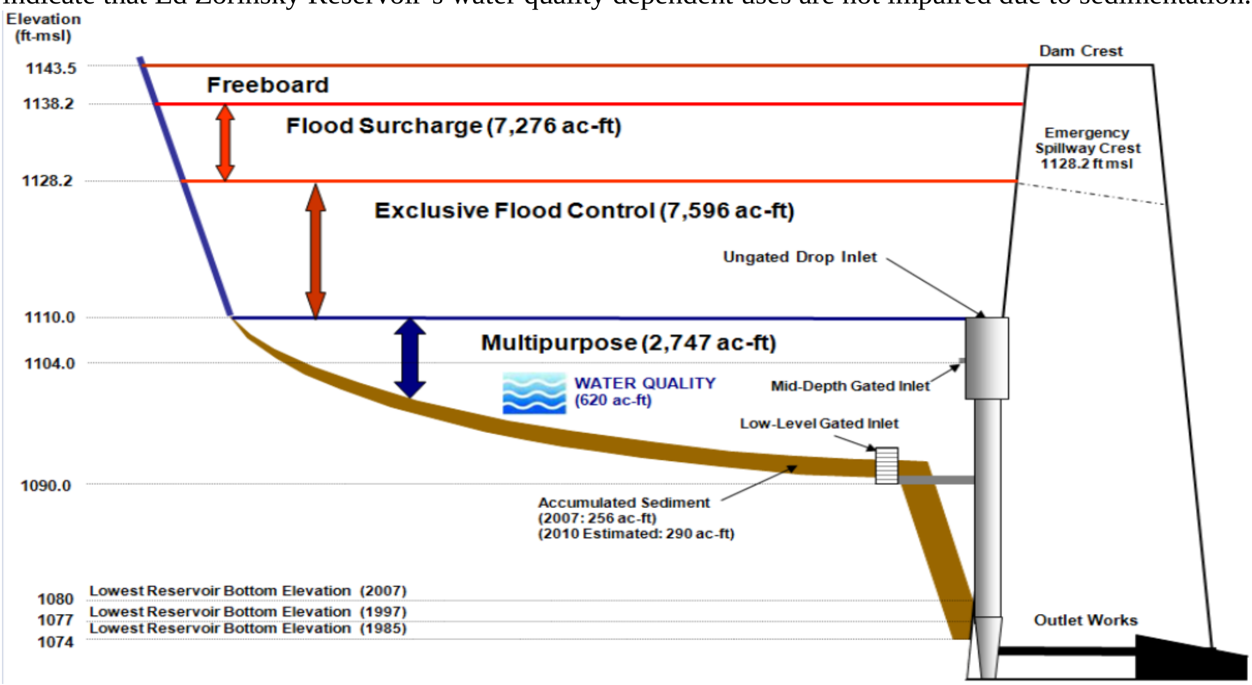

Figure 6.2. Current storage zones of Ed Zorinsky Reservoir based on the 2007 Corps survey data and estimated sedimentation.

6.1.2.1.4 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Ed Zorinsky Reservoir since the reservoir was initially filled in the early 1990's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Figure 6.3 shows the location of sites that have been monitored for water quality during the past 5 years (i.e., 2006 through 2010). The near-dam location (i.e., EZRLKND1) was been continuously monitored since 1993.

Figure 6.3. Location of sites where water quality monitoring was conducted by the District at Ed Zorinsky Reservoir during the period 2006 through 2010.

6.1.2.2 <u>Water Quality in Ed Zorinsky Reservoir</u>

6.1.2.2.1 Existing Water Quality Conditions

6.1.2.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Ed Zorinsky Reservoir at sites EZRLKND1, EZRLKML1A, EZRLKML1B, EZRLKML2, EZRLKUP1, and EZRLKUP2 from May through September during the 5-year period 2006 through 2010 are summarized in Plates 1 through 4. A review of these results indicated possible water quality concerns regarding dissolved oxygen, nutrients, and chlorophyll a.

A significant number of dissolved oxygen measurements throughout Ed Zorinsky Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plates 1- 4). All of the low dissolved oxygen measurements occurred near the bottom of the reservoir and were associated with thermal stratification. The following provision is included in Nebraska's Water Quality Standards regarding the application of water quality criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen levels measured in Ed Zorinsky Reservoir. Therefore, the measured dissolved oxygen levels below 5 mg/l are not considered exceedences of the water quality standards criteria.

Nutrient criteria defined in Nebraska's water quality standards for R13 impounded waters include: total phosphorus (50 ug/l), total nitrogen (1,000 ug/l), and chlorophyll *a* (10 ug/l). All three of these criteria were exceeded throughout Ed Zorinsky Reservoir (Plates 1- 4). The total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 78, 63, and 72 percent of the samples collected at site EZRLKND1 (i.e., near-dam) (Plate 1). At site EZRLKUP1 (i.e., upper reaches), the total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 92, 80, and 72 percent of the collected samples (Plate 4). All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" (i.e., May through September) and the reported mean values (Plates 1- 4) represent the growing season average for the 5-year period 2006 through 2010. Based on the State of Nebraska's impairment assessment methodology, the chlorophyll *a* mean values of 30 ug/l and 37 ug/l respectively determined for samples collected at site EZRLKND1 (Plate 1) and EZRLKUP1 (Plate 4) indicate impairment of the Aesthetics beneficial use of Ed Zorinsky Reservoir due to nutrients. The monitored low dissolved oxygen levels and high mean chlorophyll *a* value may also indicate impairment of the Aquatic Life beneficial use of Ed Zorinsky Reservoir also due to nutrients.

6.1.2.2.1.2 Thermal Stratification

6.1.2.2.1.2.1 Longitudinal Temperature Contour Plots

Late-spring and summer thermal stratification of Ed Zorinsky Reservoir measured during 2009 and 2010 is depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plates 5 and 6, respectively, provide longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites EZRLKND1, EZRLKML1A, EZRLKML1B, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2009 and 2010 (Plates 5 and 6). Significant thermal stratification occurred in Ed Zorinsky Reservoir from late-spring through most of the summer during 2009 and 2010. A 1° to 9°C difference between surface and bottom water temperature was measured.

6.1.2.2.1.2.2 Near-Dam Temperature Depth-Profile Plots

The depth-profile temperature measurements collected during the summer over the past 5 years at the deep water area near the dam were compiled and plotted to describe the existing summer thermal stratification of Ed Zorinsky Reservoir (Plate 7). The plotted depth-profile temperature measurements indicate that the reservoir exhibits significant thermal stratification during the summer. The deeper areas of the reservoir, in the area of the old creek channel, do not appear to mix with the upper column of water during the summer. Since Ed Zorinsky Reservoir ices over in the winter, it appears to be a dimictic lake based on the measured thermal stratification in the summer (Wetzel, 2001). Wetzel (2001) identifies lakes as dimictic if they circulate freely twice a year in the spring and fall and are directly stratified in the summer and inversely stratified under ice cover in winter.

6.1.2.2.1.3 Dissolved Oxygen Conditions

6.1.2.2.1.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Ed Zorinsky Reservoir based on depth-profile measurements taken during 2009 and 2010. Plates 8 and 9, respectively, provide longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September in 2009 and 2010. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored near the reservoir bottom throughout the summer of both years (Plates 8 and 9).

6.1.2.2.1.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

The depth-profile dissolved oxygen measurements collected during the summer over the past 5 years at the deep water area near the dam were compiled and plotted to describe the existing summer dissolved oxygen conditions of Ed Zorinsky Reservoir (Plate 10). Most of the plotted profiles indicate a significant vertical gradient in dissolved oxygen levels with most tending towards a clinograde distribution. A few of the plotted profiles indicate dissolved oxygen concentrations above 5 mg/l from the reservoir surface to the bottom. These profiles were measured in early spring or fall and are believed to be a result of thermal stratification breaking down to the depth the profile was measured as “spring turnover” ended or “fall turnover” of the reservoir approached.

6.1.2.2.1.3.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of Ed Zorinsky Reservoir with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2009 and 2010 and the District’s current

Area-Capacity Tables for the reservoir. The constructed contour plots were reviewed to identify the "worst-case" dissolved oxygen condition. The "worst-case" condition was taken to be the contour plot with the highest elevations of the 5 mg/l and 2.5 mg/l dissolved oxygen isopleths. The July 13, 2010 contour plot indicates a pool elevation of 1111.5 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1107 ft msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1102 ft-msl (Plate 9). The current District Area-Capacity Tables (2007 Survey) give storage capacities of 3,168 ac-ft for elevation 1111.5 ft-msl, 2,104 ac-ft for elevation 1107 ft-msl, and 1,217 ac-ft for elevation 1102 ft-msl. On July 13, 2010 it is estimated that 66 percent of the volume of Ed Zorinsky Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 38 percent of the reservoir volume was hypoxic.

6.1.2.2.1.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in Ed Zorinsky Reservoir indicated hypoxic conditions were prevalent throughout the summers of 2009 and 2010, longitudinal contour and depth-profile plots were constructed for ORP and pH. Near-surface and near-bottom water quality samples collected when hypoxia was present were also compared.

6.1.2.2.1.4.1 Oxidation-Reduction Potential

Plates 11 and 12, respectively, provide longitudinal ORP contour plots based on measurements taken in 2009 and 2010. The negative ORP values measured by mid- to late-summer in 2010 indicate significant reduced conditions present near the reservoir bottom. Plate 13 plots depth profiles for ORP measured during the summer over the past 5 years in the deep water area of Ed Zorinsky Reservoir near the dam. A significant vertical gradient in ORP regularly occurred in the reservoir during the summer.

6.1.2.2.1.4.2 pH

Longitudinal contour plots for pH conditions measured in 2009 and 2010 are provided, respectively, in Plates 14 and 15. The reduced conditions in the deeper water of Ed Zorinsky Reservoir seemingly lead to lower pH levels near the reservoir bottom. The lowest measured pH levels near the reservoir bottom were above the lower pH criterion of 6.5 for the protection of warmwater aquatic life. Plate 16 plots depth profiles for pH measured during the summer over the past 5 years in the deep water area of Ed Zorinsky Reservoir near the dam. A significant vertical gradient in pH regularly occurred in the reservoir during the summer.

6.1.2.2.1.4.3 Comparison of Near-Surface and Near-Bottom Water Quality Conditions

Paired near-surface and near-bottom water quality samples collected from Ed Zorinsky Reservoir during the summer when hypoxia was present were compared. Near-surface conditions were represented by samples collected within 1-meter of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site EZRLKND1 during the 5-year period 2006 through 2010. During the 5-year period a total of 25 paired samples were collected monthly from May through September. Of the 25 paired samples collected, 17 (68%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature (17), dissolved oxygen (17), oxidation-reduction potential (17), pH (17), alkalinity (15), total ammonia (15), nitrate-nitrate nitrogen (15), total phosphorus (15), and orthophosphorus (15) (Plate 17) *[Note: the number in parentheses is the number of paired observations available for each parameter]*. A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the

paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were significantly different for all the assessed parameters except nitrate-nitrite nitrogen. Parameters that were significantly lower in the near-bottom water of Ed Zorinsky Reservoir when hypoxia was present included: water temperature ($p < 0.0001$), dissolved oxygen ($p < 0.0001$), ORP ($p < 0.0001$), and pH ($p < 0.0001$). Parameters that were significantly higher in the near-bottom water included: total ammonia nitrogen ($p < 0.005$), total alkalinity ($p < 0.01$), total phosphorus ($p < 0.04$), and ortho-phosphorus ($p < 0.04$).

6.1.2.2.1.5 Water Clarity

6.1.2.2.1.5.1 Secchi Transparency

Figure 6.4 displays a box plot of the Secchi depth transparencies measured at sites EZRLKND1, EZRLKML1A, EZRLKML1B, EZRLKML2, EZRLKUP1, and EZRLKUP2 during the 5-year period 2006 through 2010 (note: the monitoring sites are oriented in an upstream to downstream direction). Secchi depth transparencies at sites EZRLKUP2 and EZRLKUP1 were similar and significantly lower than the Secchi depth transparencies at sites EZRLKML2, EZRLKML1B, EZELKML1A, and EZRLKND1 (i.e., non-overlapping inter-quartile ranges). Secchi depths measured at sites EZRLKML2, EZRLKML1B, EZRLKML1A, and EZRLKND1 were similar. The 168th street Bridge separates Ed Zorinsky Reservoir into an upper and a lower basin (Figure 6.3). The upper basin acts as a “wet” sediment retention trap for the lower basin. Sites EZRLKUP2 and EZRLKUP1 are in the upper basin, while sites EZRLKML2, EZRLKML1B, EZRLKML1A, and EZRLKND1 are in the lower basin.

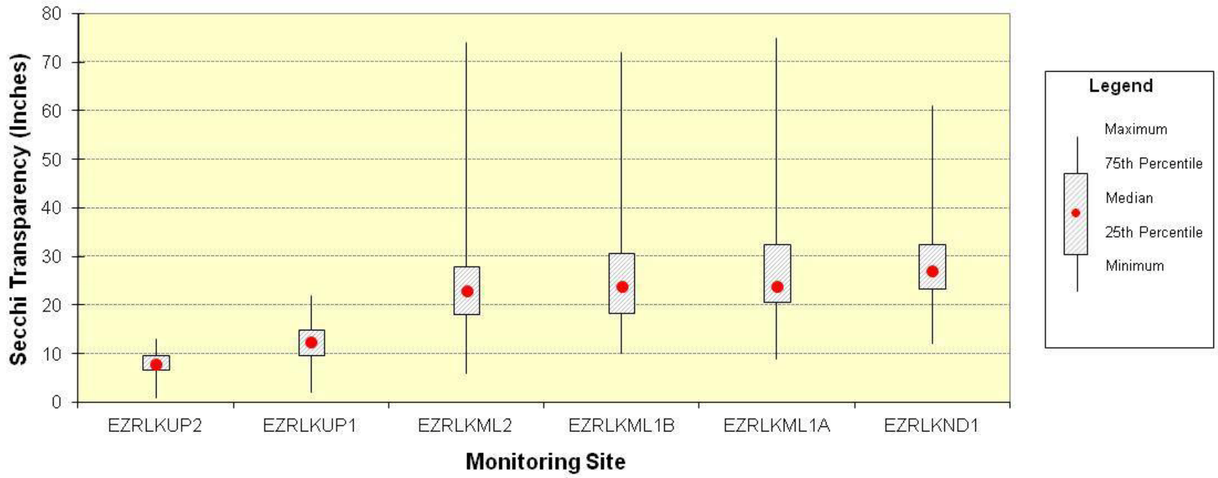

Figure 6.4. Box plot of Secchi depth transparencies measured in Ed Zorinsky Reservoir during the 5-year period 2006 through 2010. (Note: monitoring sites are oriented on the x-axis in an upstream to downstream direction.)

6.1.2.2.1.5.2 Turbidity

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level. Turbidity in water is caused by suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms. Turbidity contour plots were constructed along the length of Ed Zorinsky Reservoir based on depth-profile measurements taken during 2009 and 2010. Plates 18 and 19, respectively, provide longitudinal turbidity contour plots based on depth-profile measurements taken from May through September. The measured turbidity levels in Ed Zorinsky Reservoir varied longitudinally

with higher turbidity occurring in the upper reaches of the reservoir. Some vertical variation in turbidity was also measured.

6.1.2.2.1.6 Reservoir Trophic Status

Trophic State Index (TSI) values for Ed Zorinsky Reservoir were calculated from monitoring data collected during the 5-year period 2006 through 2010 at the near-dam ambient monitoring site (i.e., EZRLKND1). Table 6.2 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Ed Zorinsky Reservoir is in a eutrophic condition.

Table 6.2. Summary of Trophic State Index (TSI) values calculated for Ed Zorinsky Reservoir for the 5-year period 2006 through 2010.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	24	63	65	47	74
TSI(TP)	25	59	60	48	64
TSI(Chl)	25	69	73	46	83
TSI(Avg)	25	64	65	52	72

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values for the individual parameters.
Note: See Section 4.1.3 for discussion of TSI calculation.

6.1.2.2.2 Water Quality Trends (1993 through 2010)

Ed Zorinsky Reservoir reached initial fill in 1992 and water quality monitoring of the reservoir began in 1993. Water quality trends from 1993 to 2010 were determined for Ed Zorinsky Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through October at the near-dam monitoring site (i.e., EZRLKND1). Plate 20 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, it appears that Ed Zorinsky Reservoir exhibited decreasing transparency and increasing levels of chlorophyll *a* (Plate 20). No trend in total phosphorus concentrations is observable (Plate 20). Over the 18-year period since 1993, Ed Zorinsky Reservoir has generally remained in a eutrophic condition. However, if the current trend continues, the reservoir appears to be moving towards a hypereutrophic condition.

6.1.2.3 <u>Existing Water Quality Conditions of Runoff Inflows to Ed Zorinsky Reservoir</u>

Existing water quality in Box Elder Creek, above Ed Zorinsky Reservoir, was monitored under runoff conditions during the period of April through September at site EZRNF1. The site is approximately 1½ miles upstream from the reservoir (Figure 6.3). Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from “base-flow” conditions. Plate 21 summarizes water quality conditions that were monitored at site EZRNF1 under runoff conditions during the 5-year period 2006 through 2010.

6.1.3 GLENN CUNNINGHAM RESERVOIR

6.1.3.1 Background Information

6.1.3.1.1 Project Overview

The dam forming Glenn Cunningham Reservoir is located on Knight Creek, a tributary to Little Papillion Creek. The dam was completed on August 5, 1974 and the reservoir reached its initial fill on September 2, 1977. The Glenn Cunningham Reservoir watershed is 17.8 square miles. The watershed has remained largely agricultural since the dam was built in 1974; however, widespread acreage development is presently occurring.

6.1.3.1.2 Aquatic Habitat Restoration Project

An aquatic habitat restoration project was initiated at Glenn Cunningham Reservoir in 2006. To facilitate implementation of the project, the reservoir was drained in the spring of 2006. The project consisted of two phases: 1) construction of in-reservoir habitat structures and modification of the outlet structure, and 2) rehabilitation and creation of wetland habitat in the reservoir and floodplain immediately upstream of the Nebraska Hwy 36 Bridge. The project was completed in December 2008 and water quality monitoring resumed in June 2009.

6.1.3.1.3 Reservoir Storage Zones

Figure 6.5 depicts the storage zones of Glenn Cunningham Reservoir based on 2009 survey data and estimated sedimentation. These storage zones reflect the 275 ac-ft of sediment removed during the habitat restoration project. The dam intake structure was also modified as part of the ongoing aquatic habitat restoration project. It is estimated that 19 percent of the "as-built" Multipurpose Pool has been lost to sedimentation with an annual volume loss estimate of 0.56 percent.

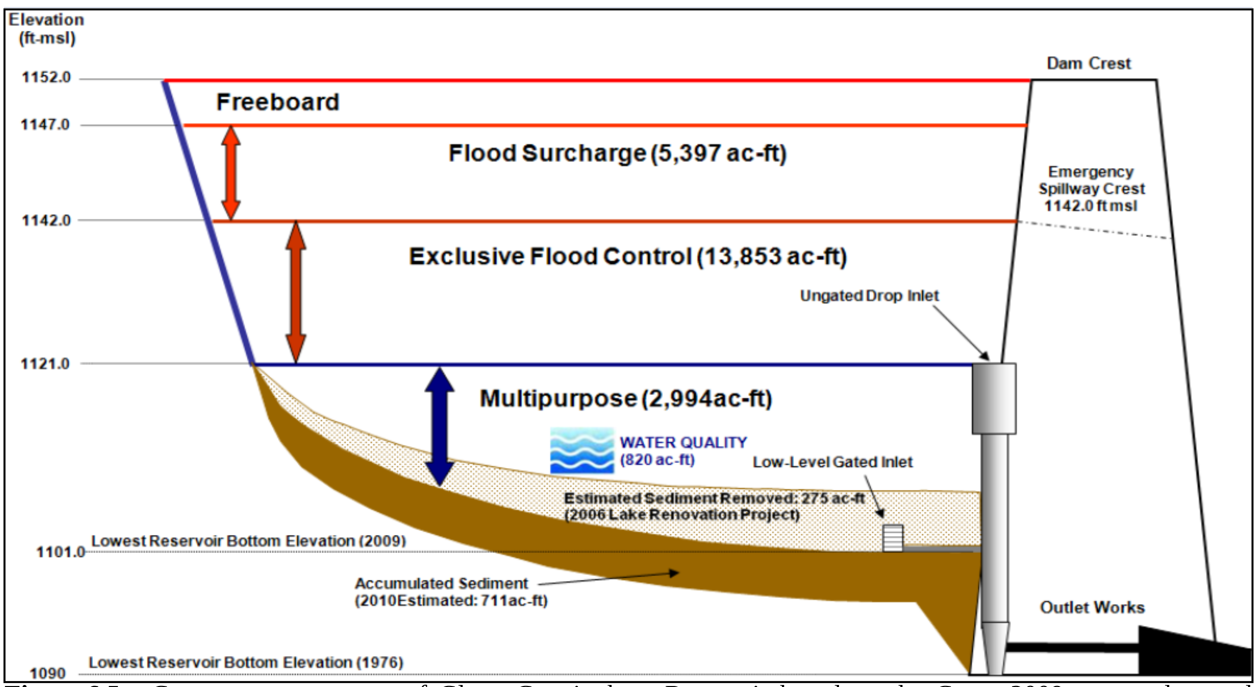

Figure 6.5. Current storage zones of Glenn Cunningham Reservoir based on the Corps 2009 survey data and estimated sedimentation.

6.1.3.1.4 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Glenn Cunningham Reservoir since the reservoir was initially filled in the late 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Figure 6.6 shows the location of the sites that have been monitored for water quality during the past 2 years (i.e., 2009 and 2010). Because the reservoir was drawn down in 2006 for aquatic habitat restoration, water quality monitoring during 2006, 2007, and 2008 only occurred at the inflow sites (i.e., GCRNFNRTH1 AND GCRNFEAST1). The near-dam location (GCRLKND1) was continuously monitored from 1980 through 2005.

6.1.3.2 Water Quality in Glenn Cunningham Reservoir

6.1.3.2.1 Existing Water Quality Conditions

6.1.3.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Glenn Cunningham Reservoir at sites GCRLKND1, GCRLKML1 and GCRLKUP1 from May through September during the 2-year period 2009 through 2010 are summarized, respectively, in Plates 22 and 23. Water quality monitoring was not conducted at the sites in 2006 through 2008 due to the reservoir being drawn down for renovation. A review of the results indicated possible water quality concerns regarding dissolved oxygen, chlorophyll *a*, and nutrients.

A significant number of dissolved oxygen measurements throughout Glenn Cunningham Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plates 22 and 23). All of the low dissolved oxygen measurements occurred near the reservoir bottom and were associated with thermal stratification. The following provision is included in Nebraska's Water Quality Standards regarding the application of water quality criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen levels measured in Glenn Cunningham Reservoir. Therefore, the measured dissolved oxygen levels below 5 mg/l are not considered exceedences of the water quality standards criteria.

Nutrient criteria defined in Nebraska's water quality standards for R14 impounded waters include: total phosphorus (50 ug/l), total nitrogen (1,000 ug/l), and chlorophyll *a* (10 ug/l). All three of these criteria were exceeded Glenn Cunningham Reservoir (Plates 22 and 23). The chlorophyll *a* criterion was exceeded by 100 percent of the "lab analyzed" samples taken in the reservoir. The total phosphorus and total nitrogen criteria were both exceeded by 72 percent of the samples. All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" (i.e., May through September) and the reported mean values (Plates 22 and 23) represent the growing season average for the 2-year period 2009 through 2010. Based on the State of Nebraska's impairment assessment methodology the mean total phosphorus (0.08 mg/l), total nitrogen (1.21 mg/l), and chlorophyll *a* (31 ug/l) values indicate impairment of the aquatic life use.

Due to the recent habitat restoration project Nebraska's water quality standards place Glenn Cunningham Reservoir in category 4R. Nutrient assessment of category 4R designated waters may be misleading due to a trophic upsurge upon refill which is typically followed by a period of decline. Reservoirs may be placed in the category for a period of up to 8 years.

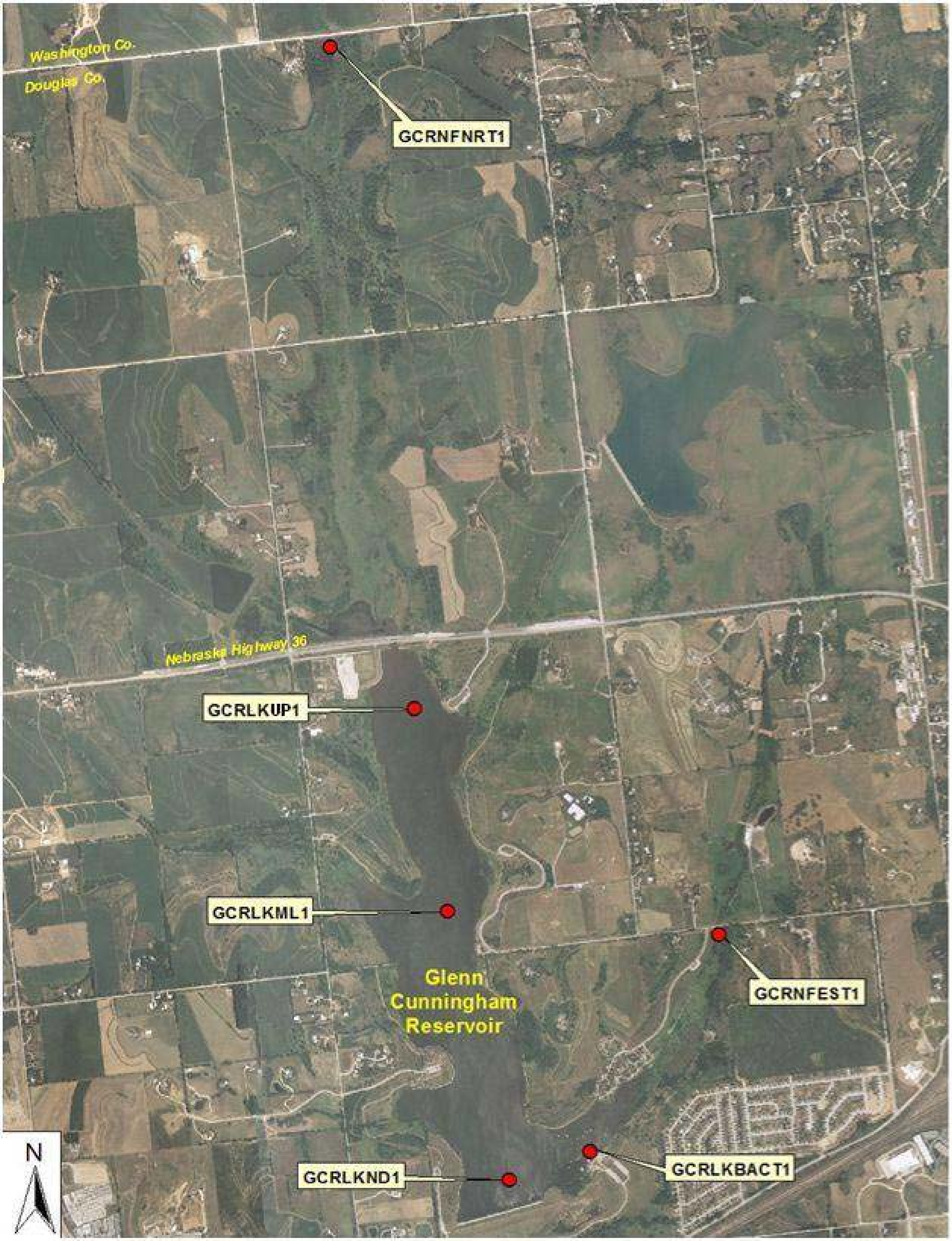

Figure 6.6. Location of sites where water quality monitoring was conducted by the District at Glenn Cunningham Reservoir during the 5-year period 2006 through 2010.

6.1.3.2.1.2 Thermal Stratification and Dissolved Oxygen Conditions

6.1.3.2.1.2.1 Near-Dam Temperature Depth-Profile Plots

The depth-profile temperature measurements collected during the summers of 2009 and 2010 at the deep water area near the dam were compiled and plotted to describe the existing summer thermal stratification of Glenn Cunningham Reservoir (Plate 27). The plotted depth-profile temperature measurements indicate that the reservoir exhibits periodic thermal stratification during the summer (Plate 27). Since Glenn Cunnigham Reservoir ices over in the winter, it appears to be a dimictic lake based on the measured thermal stratification in the summer (Wetzel, 2001). Wetzel (2001) identifies lakes as dimictic if they circulate freely twice a year in the spring and fall and are directly stratified in the summer and inversely stratified under ice cover in winter.

6.1.3.2.1.2.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

The depth-profile dissolved oxygen measurements collected during the summers of 2009 and 2010 at the deep water area near the dam were complied and plotted to describe the existing summer dissolved oxygen conditions of Glenn Cunningham Reservoir (Plate 30). On several occasions, there was a significant vertical gradient in summer dissolved oxygen levels in Glenn Cunningham Reservoir, with the vertical dissolved oxygen profiles exhibiting a clinograde distribution. However, there were times when dissolved oxygen levels were above 5 mg/l from the reservoir surface to the bottom (Plate 30). There appears to be enough thermal stratification of Glenn Cunningham Reservoir during the summer to regularly allow for significant dissolved oxygen degradation near the reservoir bottom.

6.1.3.2.1.3 Water Clarity

Figure 6.7 displays a box plot of the Secchi depth transparencies measured at the three in-reservoir monitoring sites (i.e., GCRLKND1, GCRLKML1, and GCRLKUP1) during the 2-year period 2009 through 2010 (note: the monitoring sites are oriented in an upstream to downstream direction). The Secchi depth transparencies at the upper basin site were significantly lower than those measured at the other two sites.

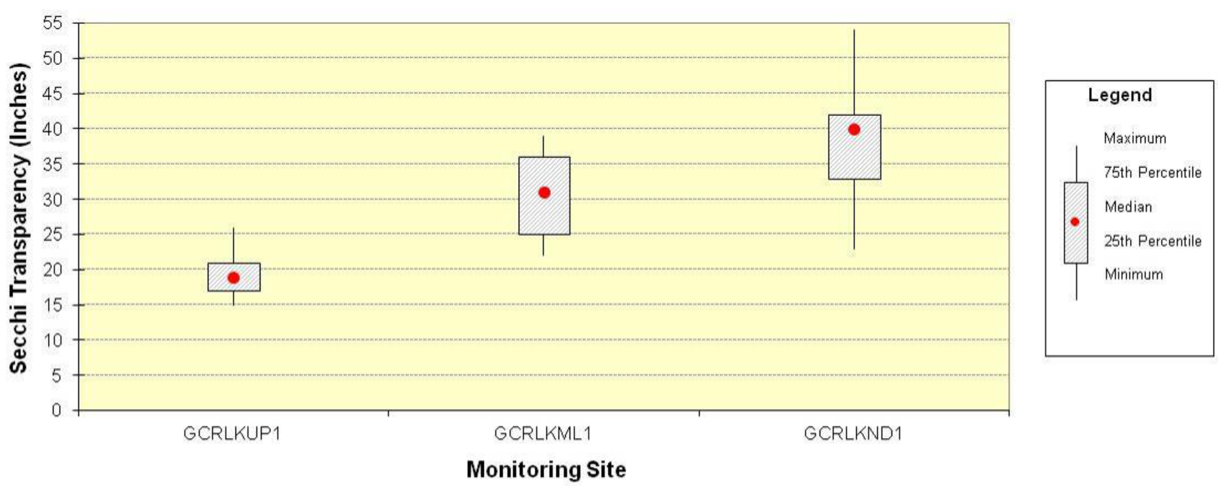

Figure 6.7 Box plot of Secchi depth transparencies measured in Glenn Cunningham Reservoir during the 2-year period 2009 through 2010. (Note: monitoring sites are oriented on the x-axis in an upstream to downstream direction.)**.**

6.1.3.2.1.4 Reservoir Trophic Status

Trophic State Index (TSI) values for Glenn Cunningham Reservoir were calculated from monitoring data collected during the 2-year period 2009 through 2010 at the near-dam ambient monitoring site (i.e., GCRLKND1). Table 6.3 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Glenn Cunningham Reservoir was in a eutrophic condition.

Table 6.3. Summary of Trophic State Index (TSI) values calculated for Glenn Cunningham Reservoir for the 2-year period 2009 through 2010.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	9	61	60	55	68
TSI(TP)	9	58	59	55	61
TSI(Chl)	9	72	74	65	77
TSI(Avg)	9	64	63	61	66

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values for the individual parameters.
Note: See Section 4.1.3 for discussion of TSI calculation.

6.1.3.2.1.5 Bacteria Monitoring

A designated swimming beach is not located on Glenn Cunningham Reservoir; however, the reservoir is used extensively for sailing and wind surfing. Since these recreational uses can lead to direct contact with water, bacteria monitoring was conducted at the reservoir. During the 2-year period 2009 through 2010, bacteria samples were collected weekly from May through September near the marina boat ramp on Glenn Cunningham Reservoir (i.e., site GCRLKBACT1) (Figure 6.6). Table 6.4 summarizes the results of the bacteria sampling. The "running 5-week" geometric means were calculated as running geometric means for five consecutive weekly bacteria samples through the recreational season (i.e., May through September). The "pooled" geomeans were determined by pooling all the weekly bacteria samples collected during the recreational season over the 2-year period and calculating a single geomean. All nondetects were set to 1 to calculate geomeans. The sampling results were compared to the following Nebraska water quality criteria for bacteria:

<u>Fecal Coliform:</u>
Bacteria of the fecal coliform group should not exceed a geometric mean of 200/100ml, nor equal or exceed 400/100ml, in more than 10% of the samples. These criteria are based on a minimum of five samples taken within a 30-day period.

<u>*E. coli*</u>:
E. coli bacteria should not exceed a geometric mean of 126/100ml. For increased confidence of the criteria, the geometric mean should be based on a minimum of five samples taken within a 30-day period. Single sample maximum allowable density for designated bathing beaches is 235/100ml.

The pooled geomeans were compared to the State of Nebraska's impairment assessment criteria regarding the assessment of the Primary Contact Recreation beneficial use using fecal coliform and *E. coli* bacteria data. Based on those criteria a Primary Contact Recreation use in Glenn Cunningham Reservoir is not impaired due to bacteria. The higher bacteria levels monitored in the reservoir are believed to be associated with runoff events.

Table 6.4. Summary of weekly (May through September) bacteria samples collected at Glenn Cunningham Reservoir (i.e., site GCRLKBACT1) during the 2-year period 2009 through 2010.

Fecal Coliform Bacteria – Individual Samples		***E. coli* – Individual Samples**	
Number of Samples	42	Number of Samples	42
Mean (cfu/100ml)	33	Mean (cfu/100ml)	43
Median (cfu/100ml)	9	Median (cfu/100ml)	10
Minimum (cfu/100ml)	n.d.	Minimum (cfu/100ml)	n.d.
Maximum (cfu/100ml)	226	Maximum (cfu/100ml)	313
Percent of samples exceeding 400/100ml	0%	Percent of samples exceeding 235/100ml	5%
Fecal Coliform Bacteria – Running 5-Week Geomean		***E. coli* – Running 5-Week Geomean**	
Number of Geomeans	34	Number of Geomeans	34
Average	15	Average	17
Median	15	Median	16
Minimum	2	Minimum	2
Maximum	36	Maximum	36
Percent of Geomeans exceeding 200/100ml	6%	Percent of Geomeans exceeding 126/100ml	9%
Fecal Coliform Bacteria – Pooled Geomean		***E. coli* – Pooled Geomean**	
Pooled Geomean (cfu/100ml)	26	Pooled Geomean (cfu/100ml)	14

n.d. = non-detected.
Note: Non-detected values set to 1 to calculate mean and geomean.

6.1.3.2.2 Water Quality Trends (1980 through 2010)

Water quality trends from 1980 to 2010 were determined for Glenn Cunningham Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through September at the near-dam monitoring site (i.e., GCRLKND1). Plate 31 displays a scatter-plot of the collected data for the four parameters and a linear regression line for data collected before and after the habitat restoration project. The determined trends indicated that Glenn Cunningham Reservoir exhibited decreasing transparency and increasing levels of total phosphorus. Data collected following the restoration project indicate a declining spike in secchi transparency and chlorophyll *a* concentration. Glenn Cunningham Reservoir went from a hypereutrophic to eutrophic condition in 2010 (Plate 31).

6.1.3.3 Existing Water Quality Conditions of Runoff Inflows to Glenn Cunningham Reservoir

Existing water quality in the north and east inflows to Glenn Cunningham Reservoir were monitored under runoff conditions, during the period of April through September, respectively at sites GCRNFNRT1 and GCRNFEST1. Site GCRNFNRT1 is 2 miles upstream from the reservoir, and site GCRNFEST1 is approximately ½ mile upstream of the reservoir (Figure 6.6). Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from "base-flow" conditions. Plate 32 and 33, respectively; summarize water quality conditions that were monitored at sites GCRNFNRT1 and GCRNFEST1 under runoff conditions during the period 2006 through 2010. Levels of atrazine in the Knight Creek inflow to Glen Cunningham Reservoir may be a concern as 1 of 11 (9%) collected samples exceeded the chronic criteria of 12 ug/l for the protection of aquatic life. The criteria exceedences occurred during spring runoff (i.e., April).

6.1.4 STANDING BEAR RESERVOIR

6.1.4.1 Background Information

6.1.4.1.1 Project Overview

The dam forming Standing Bear Reservoir is located on an unnamed tributary of Big Papillion Creek. The Standing Bear Reservoir watershed is 6.0 square miles. The watershed was largely agricultural when the dam was built in 1972; however since then, the watershed has undergone extensive urbanization with the growth of Omaha. The reservoir reached its initial fill in October 1977.

6.1.4.1.2 Standing Bear Dam Intake Structure

The reinforced concrete intake structure at Standing Bear dam has uncontrolled openings at two levels in addition to a low-level gate. Uncontrolled flood control weirs are at elevation 1109 ft-msl and smaller openings for the conservation pool are at elevation 1104 ft-msl. The inlet to the low-level gate is located 302 feet upstream of the intake structure at elevation 1080 ft-msl. The ungated openings and the low-level inlet are protected with metal trash racks.

6.1.4.1.3 Reservoir Storage Zones

Figure 6.8 depicts the current storage zones of Standing Bear Reservoir based on 2009 survey data and estimated sedimentation. It is estimated that 18 to 25 percent of the "as-built" Multipurpose Pool had been lost to sedimentation as of 2010. Annual volume loss is estimated to be 0.50 to 0.73 percent. According to the State of Nebraska's impairment assessment methodology Standing Bear Reservoir's water quality dependent uses may be marginally impaired due to sedimentation.

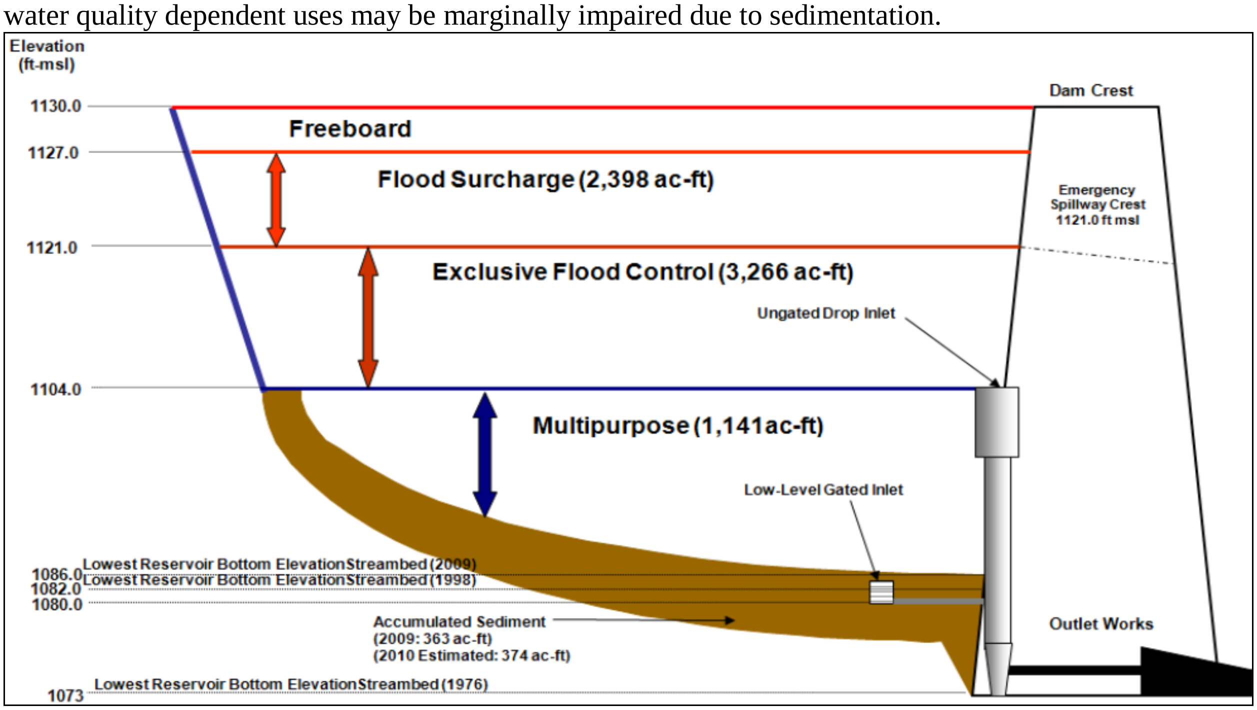

Figure 6.8. Current storage zones of Standing Bear Reservoir based on the 2009 Corps survey data and estimated sedimentation**.**

6.1.4.1.4 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Standing Bear Reservoir since the reservoir was initially filled in the late 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Figure 6.9 shows the location of the sites

that have been monitored for water quality during the past 5 years (i.e., 2006 through 2010). The near-dam location (STBLKND1) has been continuously monitored since 1980.

6.1.4.2 Water Quality in Standing Bear Reservoir

6.1.4.2.1 Existing Water Quality Conditions

6.1.4.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Standing Bear Reservoir at sites STBLKND1 and STBLKML1 from May through September during the 5-year period 2006 through 2010 are summarized, respectively, in Plates 35 and 36. A review of these results indicated possible water quality concerns regarding dissolved oxygen, total ammonia, nutrients, and mercury.

A significant number of dissolved oxygen measurements throughout Standing Bear Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plates 35 and 36). All of the low dissolved oxygen measurements occurred near the reservoir bottom and were associated with thermal stratification. The following provision is included in Nebraska's Water Quality Standards regarding the application of water quality criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen levels measured in Standing Bear Reservoir. Therefore, the measured dissolved oxygen levels below 5 mg/l are not considered exceedences of the water quality standards criteria.

The chronic ammonia criteria for the protection of warmwater aquatic life were seemingly exceeded in Standing Bear Reservoir in the area near the dam. Ammonia criteria are pH and temperature dependant, and the criteria cited are based on median values that may or may not represent conditions when the higher ammonia occurred. Also, the exceedences of the criteria were measured in near-bottom samples, and the numeric ammonia criteria may not be applicable if thermal stratification was present. The higher near-bottom ammonia conditions may be associated with the reduction of nitrogen as dissolved oxygen is degraded in the hypolimnion during thermal stratification.

The chronic mercury criterion for the protection of aquatic life was exceeded in one of five samples collected at the near-dam site (i.e., STBLKND1). The acute mercury criterion was not exceeded. At this time the chronic exceedence at the near-dam site is considered to be a possible outlier.

Nutrient criteria defined in Nebraska's water quality standards for R13 impounded waters include: total phosphorus (50 ug/l), total nitrogen (1,000 ug/l), and chlorophyll *a* (10 ug/l). All three of these criteria were exceeded throughout Standing Bear Reservoir (Plates 35 and 36). The total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 70, 68, and 69 percent of the samples collected at site STBLKND1. All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" (i.e., May through September) and the reported mean values represent the growing season average for the 5-year period 2006 through 2010. Based on the State of Nebraska's impairment assessment methodology, the chlorophyll *a* mean value of 40 ug/l for samples collected at site STBLKND1 indicates impairment of the aesthetic beneficial use of Standing Bear Reservoir due to nutrients. The monitored low dissolved oxygen levels and high mean chlorophyll *a* value may also indicate impairment of the aquatic life beneficial use of Standing Bear Reservoir also due to nutrients.

Figure 6.9. Location of sites where water quality monitoring was conducted by the District at Standing Bear Reservoir during the period 2004 through 2008.

6.1.4.2.1.2 Thermal Stratification

6.1.4.2.1.2.1 Longitudinal Temperature Contour Plots

Late-spring and summer thermal stratification of Standing Bear Reservoir during 2009 and 2010 is depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plates 37 and 38, respectively, provide longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites STBLKND1, STBLKML1, and STBLKUPN1 in 2009 and 2010. Plates 37 and 38 indicate that significant thermal stratification was present in Standing Bear Reservoir during late-spring to mid-summer during 2009 and 2010. A maximum difference of about 8°C was measured between surface and bottom water temperatures. The thermal stratification in both years persisted throughout the summer (Plate 38).

6.1.4.2.1.2.2 Near-Dam Temperature Depth-Profile Plots

The depth-profile temperature measurements collected during the summer over the past 5 years at the deep water area near the dam were compiled and plotted to describe the existing summer thermal stratification of Standing Bear Reservoir (Plate 39). The plotted depth-profile temperature measurements indicate that the reservoir exhibits regular thermal stratification during the summer (Plate 39). The deeper areas of the reservoir in the area of the old creek channel do not appear to mix with the upper column of water in the summer. Since Standing Bear Reservoir ices over in the winter, it appears to be a cold dimictic lake based on the measured thermal stratification in the summer (Wetzel, 2001).

6.1.4.2.1.3 Dissolved Oxygen Conditions

6.1.4.2.1.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Standing Bear Reservoir based on depth-profile measurements taken during 2009 and 2010. Plates 40 and 41, respectively, provide longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September in 2009 and 2010. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored near the reservoir bottom throughout the summer of both years (Plate 41).

6.1.4.2.1.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

The depth-profile dissolved oxygen measurements collected during the summer over the past 5 years at the deep water area near the dam were compiled and plotted to describe the existing summer dissolved oxygen conditions of Standing Bear Reservoir (Plate 42). Most of the plotted profiles indicate a significant vertical gradient in dissolved oxygen levels with most tending towards a clinograde distribution (Plate 42). One of the plotted profiles indicated a dissolved oxygen concentrations of about 9.5 mg/l from the reservoir surface to the bottom (Plate 42). This profile was measured in early spring (i.e., early-May 2010) and is believed to be a result of thermal stratification breaking down and the water column mixing as “spring turnover” of the reservoir occurred.

6.1.4.2.1.3.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of Standing Bear Reservoir with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2009 and 2010 and the District’s current Area-Capacity Tables for the reservoir. The constructed contour plots were reviewed to identify the “worst-case” dissolved oxygen condition. The “worst-case” condition was taken to be the contour plot with the highest elevations of the 5 mg/l and 2.5 mg/l dissolved oxygen isopleths. The August 10,

2010 contour plot indicates a pool elevation of 1104.2 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1101.2 ft msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1098.6 ft-msl (Plate 42). The current District Area-Capacity Tables (2009 Survey) give storage capacities of 1,166 ac-ft for elevation 1104.2 ft-msl, 826 ac-ft for elevation 1101.2 ft-msl, and 578 ac-ft for elevation 1098.6 ft-msl. On August 10, 2010 it is estimated that 71 percent of the volume of Standing Bear Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 50 percent of the reservoir volume was hypoxic.

6.1.4.2.1.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in Standing Bear Reservoir indicated hypoxic conditions were prevalent throughout the summers of 2009 and 2010, longitudinal contour and depth-profile plots were constructed for ORP and pH. Near-surface and near-bottom water quality samples collected when hypoxia was present were also compared.

6.1.4.2.1.4.1 Oxidation-Reduction Potential

Plates 43 and 44, respectively, provide longitudinal ORP contour plots based on measurements taken in 2009 and 2010. The negative ORP values measured by mid- to late-summer in both years indicate significant reduced conditions present near the bottom of Standing Bear Reservoir (Plate 43 and 44). Plate 45 plots depth profiles for ORP measured during the summer over the past 5 years in the deep water area of Standing Bear Reservoir near the dam. A significant vertical gradient in ORP regularly occurred in the reservoir during the summer (Plate 45).

6.1.4.2.1.4.2 pH

Longitudinal contour plots for pH conditions measured in 2009 and 2010 are provided, respectively, in Plates 46 and 47. The reduced conditions in the deeper water of Standing Bear Reservoir seemingly lead to in lower pH levels near the reservoir bottom (Plates 46 and 47). The lowest measured pH levels near the reservoir bottom were above the lower pH criterion of 6.5 for the protection of warmwater aquatic life. The highest measured pH levels near the reservoir surface were above the upper pH criterion of 6.5 for the protection of warmwater aquatic life. Plate 48 plots depth profiles for pH measured during the summer over the past 5 years in the deep water area of Standing Bear Reservoir near the dam. A significant vertical gradient in pH regularly occurred in the reservoir during the summer (Plate 48).

6.1.4.2.1.4.3 Comparison of Near-Surface and Near-Bottom Water Quality Conditions

Paired near-surface and near-bottom water quality samples collected from Standing Bear Reservoir during the summer when hypoxia was present were compared. Near-surface conditions were represented by samples collected within 1-meter of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site STBLKND1 during the 5-year period 2009 through 2010. During the 5-year period a total of 25 paired samples were collected monthly from May through September. Of the 25 paired samples collected, 19 (76%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature (19), dissolved oxygen (19), oxidation-reduction potential (19), pH (18), total ammonia (19), nitrate-nitrate nitrogen (19), alkalinity (19), total phosphorus (19), and orthophosphorus (19) (Plate 49) *[Note: the number in parentheses is the number of paired observations available for each parameter]*. A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the

paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were significantly different for all the assessed parameters except nitrate-nitrite nitrogen. Parameters that were significantly lower in the near-bottom water of Standing Bear Reservoir when hypoxia was present included: water temperature ($p < 0.0001$), dissolved oxygen ($p < 0.0001$), ORP ($p < 0.0001$), and pH ($p < 0.0001$). Parameters that were significantly higher in the near-bottom water included: total ammonia nitrogen ($p < 0.01$), total alkalinity ($p < 0.001$), total phosphorus ($p < 0.05$), and ortho-phosphorus ($p < 0.001$).

6.1.4.2.1.5 Water Clarity

6.1.4.2.1.5.1 <u>Secchi Transparency</u>

Figure 6.10 displays a box plot of the Secchi depth transparencies measured at sites STBLKND1, STBLKML1, STBLKUPN1 and STBLKUPS1 from 2008 to 2010 (note: the monitoring sites are oriented in an upstream to downstream direction). Secchi depth transparency at site STBLKUPS1 was significantly lower than the Secchi depth transparencies measured at sites STBLKML1 and STBLKND1 (i.e., non-overlapping inter-quartile ranges). The maximum Secchi depth measured at site STBLKUPS1 was significantly lower than that measured at site STBLKUPN1 (Figure 6.10).

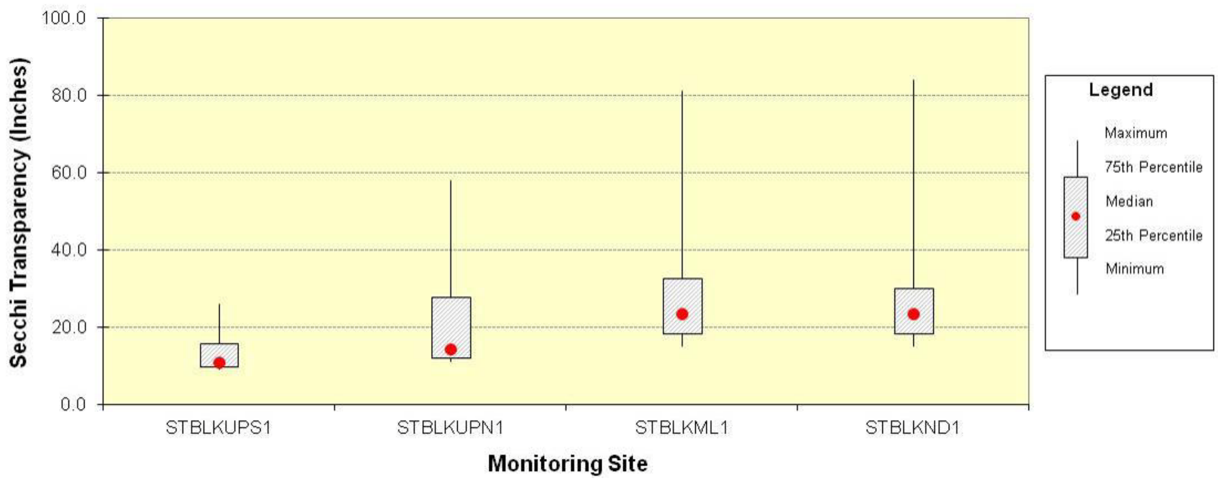

Figure 6.10. Box plot of Secchi depth transparencies measured in Standing Bear Reservoir from 2008 to 2010. (Note: monitoring sites are oriented on the x-axis in an upstream to downstream direction.)**.**

6.1.4.2.1.5.2 <u>Turbidity</u>

Turbidity contour plots were constructed along the length of Standing Bear Reservoir based on depth-profile measurements taken during 2009 and 2010. Plates 50 and 51, respectively, provide longitudinal turbidity contour plots based on depth-profile measurements taken from May through September. As seen in Plates 50 and 51, turbidity levels in Ed Zorinsky Reservoir vary longitudinally from the dam to reservoir's upper reaches, with turbidity levels being higher in the upper reaches of the reservoir. Some vertical variation in turbidity also occurs (Plates 50 and 51).

6.1.4.2.1.6 Reservoir Trophic Status

Trophic State Index (TSI) values for Standing Bear Reservoir were calculated from monitoring data collected during the 5-year period 2006 through 2010 at the near-dam ambient monitoring site (i.e., STBLKND1). Table 6.5 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Standing Bear Reservoir is in a eutrophic to hypereutrophic condition.

Table 6.5. Summary of Trophic State Index (TSI) values calculated for Standing Bear Reservoir for the 5-year period 2006 through 2010.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	25	65	65	49	74
TSI(TP)	25	59	61	41	70
TSI(Chl)	25	71	78	40	85
TSI(Avg)	25	65	67	51	75

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values for the individual parameters.

Note: See Section 4.1.3 for discussion of TSI calculation.

6.1.4.2.2 Water Quality Trends (1980 through 2010)

Water quality trends from 1980 to 2010 were determined for Standing Bear Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through September at the near-dam monitoring site (i.e., STBLKND1). Plate 52 displays a scatter-plot of the collected data for the four parameters and a linear regression line. The determined trend indicates that Standing Bear Reservoir exhibited increasing chlorophyll *a* levels. No trend in total phosphorus, water transparency, or TSI is observable. Over the 31-year period since 1980, Standing Bear Reservoir has remained in a eutrophic to hypereutrophic condition (Plate 52).

6.1.4.3 <u>Existing Water Quality Conditions of Runoff Inflows to Standing Bear Reservoir</u>

Existing water quality in the north and south inflows to Standing Bear Reservoir were monitored, respectively, at sites STBNFNRT1 and STBNFSTH1 under runoff conditions during the period of April through September. Both sites are approximately ¼ mile upstream of the reservoir (Figure 6.9). Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from "base-flow" conditions. Plates 53 and 54, respectively, summarize water quality conditions that were monitored at sites STBNFNRT1 and STBNFSTH1 under runoff conditions during the 5-year period 2006 through 2010.

6.1.5 WEHRSPANN RESERVOIR

6.1.5.1 <u>Background Information</u>

6.1.5.1.1 Project Overview

The dam forming Wehrspann Reservoir is located on a tributary to the South Branch Papillion Creek. The dam was completed on September 21, 1982 and the reservoir reached its initial fill on May 26, 1987. The Wehrspann Reservoir watershed is 13.1 square miles. The watershed was largely agricultural when the dam was built in 1982. Recently however, the watershed has undergone increased urbanization with the growth of Gretna and acreage development.

6.1.5.1.2 Aquatic Habitat Improvement and Water Quality Management Project

A Corps Section 1135 aquatic habitat improvement and water quality management project was completed at Wehrspann Reservoir in 1999. The project consisted of a sediment control structure,

sediment detention pond/wetlands, and tree and shrub mitigation plantings. The sediment control structure dam was located approximately ½ mile upstream of the reservoir (see Figure 6.12). A detention area was formed upstream of the sediment dam to capture and store sediments that would enter Wehrspann Reservoir. The natural detention area was further excavated and graded to maximize retention volume and wetlands creation. The sediment storage area will ultimately become a wet meadow-scrub wetland-grassland mosaic, unless sediment that collects is periodically removed. The detention area was designed to ultimately fill with sediment to the top of the spillway crest elevation of 1117 ft-msl. The detention area has a design capacity of 469 ac-ft with a maximum surface area of approximately 76 acres. A nonpoint source water quality management project to educate landowners and implement best management practices (BMPs) was also implemented in the watershed when the Section 1135 project was constructed.

6.1.5.1.3 Wehrspann Dam Intake Structure

The reinforced concrete intake structure has two upper level intakes (invert elevations 1096.0 and 1103.4 ft-msl), an intermediate intake (invert elevation 1090.0 ft-msl), and also a low-level intake (invert elevation 1074.0 ft-msl). The upper level intakes are uncontrolled. The low-level intake is provided with a slide gate to allow draining of the reservoir. The intermediate intake is a 6-inch diameter slide gate for flow augmentation releases. A low-level inlet is constructed 130 feet upstream of the intake tower. The inlet is provided with a trash rack and emergency bulkhead to allow closure with the gate open. A 30-inch reinforced concrete pipe connects the low-level inlet to the intake structure.

6.1.5.1.4 Reservoir Storage Zones

Figure 6.11 depicts the current storage zones of Wehrspann Reservoir based on the 2009 Corps survey data and estimated sedimentation. It is estimated that 13 to 17 percent of the "as-built" Multipurpose Pool had been lost to sedimentation as of 2010 with the annual volume loss estimated to be 0.58 to 0.73 percent. Based on the State of Nebraska's impairment assessment methodology, these values indicate that Wehrspann Reservoir's water quality dependent uses are not impaired due to sedimentation.

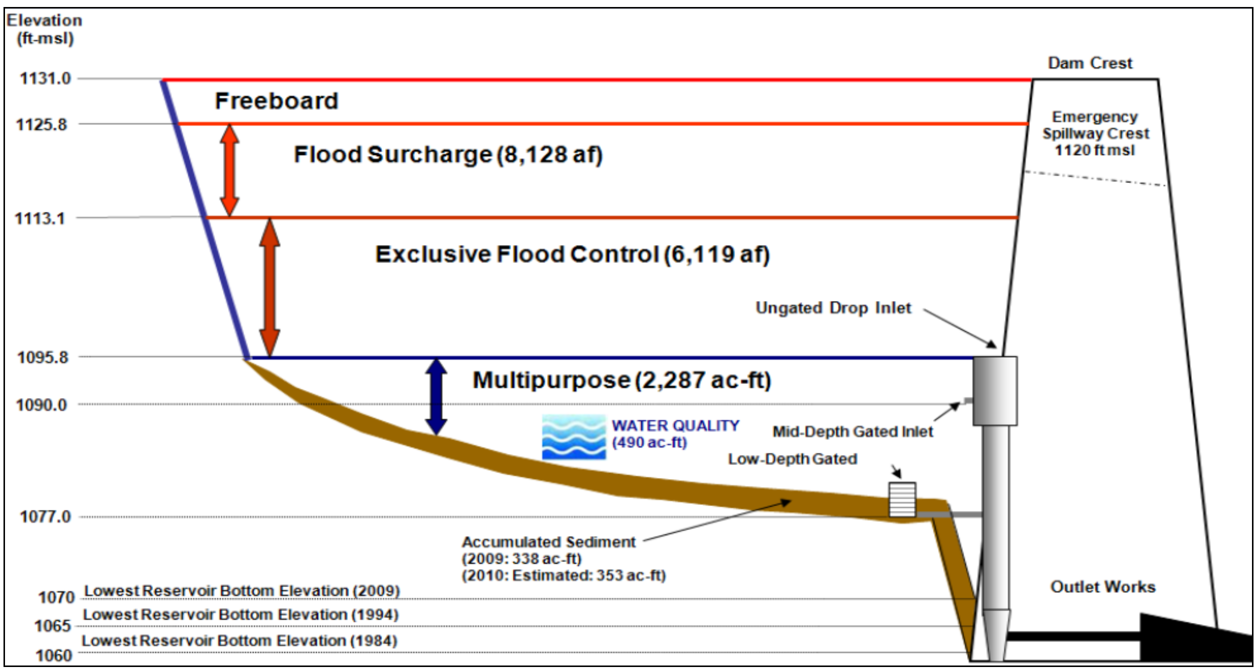

Figure 6.11. Current storage zones of Wehrspann Reservoir based on the 2009 Corps survey data and estimated sedimentation**.**

6.1.5.1.5 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Wehrspann Reservoir since the reservoir was initially filled in the late 1980's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Figure 6.12 shows the location of the sites that have been monitored for water quality during the past 5 years (i.e., 2006 through 2010). The near-dam location (WEHLKND1) has been continuously monitored since 1986.

6.1.5.2 <u>Water Quality in Wehrspann Reservoir</u>

6.1.5.2.1 Existing Water Quality Conditions

6.1.5.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Wehrspann Reservoir at sites WEHLKND1 and WEHLKML1 from May through September during the 5-year period 2006 through 2010 are summarized, respectively, in Plates 55 and 56. A review of these results indicated possible water quality concerns regarding dissolved oxygen, total ammonia, and nutrients.

A significant number of dissolved oxygen measurements throughout Wehrspann Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plates 55 and 58). All of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and appeared to be associated with a slight thermal stratification. Nebraska's Water Quality Standards makes the following provision regarding the application of the State's water quality standards' criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen situation in Wehrspann Reservoir, and the measured dissolved oxygen levels below 5 mg/l are not considered to be a water quality standards non-attainment situation.

The chronic ammonia criterion for the protection of warmwater aquatic life was seemingly exceeded in Wehrspann Reservoir in the area near the dam. Ammonia criteria are pH and temperature dependant, and the criteria cited are based on median values that may or may not represent conditions when the higher ammonia occurred. Also, the four values exceeding the criterion were measured in near-bottom samples, and the numeric ammonia criteria may not be applicable if thermal stratification was present. The higher near-bottom ammonia conditions may be associated with the reduction of nitrogen as dissolved oxygen is degraded in the hypolimnion during thermal stratification.

Nutrient criteria defined in Nebraska's water quality standards for R13 impounded waters include: total phosphorus (50 ug/l), total nitrogen (1,000 ug/l), and chlorophyll *a* (10 ug/l). All three of these criteria were exceeded throughout Wehrspann Reservoir (Plates 55 and 56). The total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 90, 72, and 72 percent of the samples collected at site WEHLKND1 (i.e., near-dam) (Plate 49). All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" (i.e., May through September) and the reported mean values represent the growing season average for the 5-year period 2006 through 2010. Based on the State of Nebraska's impairment assessment methodology, the chlorophyll *a* mean value of 47 ug/l and the total phosphorus mean value of 0.1 ug/l for samples collected at site WEHLKND1 (Plate 55) indicate impairment of the Aesthetics beneficial use of Wehrspann Reservoir due to nutrients. The monitored low dissolved oxygen levels and high mean chlorophyll *a* value indicate impairment of the Aquatic Life beneficial use of Wehrspann Reservoir also due to nutrients.

Figure 6.12. Location of sites where water quality monitoring was conducted by the District at Wehrspann Reservoir during the period 2006 through 2010.

6.1.5.2.1.2 Thermal Stratification

6.1.5.2.1.2.1 Longitudinal Temperature Contour Plots

Late-spring and summer thermal stratification of Wehrspann Reservoir measured during 2009 and 2010 is depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plates 51 and 52, respectively, provide longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites WEHLKND1, WEHLKML1, and WEHLKUP1 in 2009 and 2010. These temperature plots indicate that thermal stratification was present in Wehrspann Reservoir during the early summer of 2009 and late spring of 2010, and the extent of the stratification appeared to have weakened in September of both years. The greatest monitored difference between surface and bottom water temperatures was 7°C (Plates 57 and 58).

6.1.5.2.1.2.2 Near-Dam Temperature Depth-Profile Plots

The depth-profile temperature measurements collected during the summer over the past 5 years at the deep water area near the dam were compiled and plotted to describe the existing summer thermal stratification of Wehrspann Reservoir (Plate 59). The plotted depth-profile temperature measurements indicate that the reservoir exhibits thermal stratification during the summer (Plates 57, 58, and 59). The deeper portions of the reservoir in the area of the old creek channel appear to resist mixing with the upper column of water through mid-summer. Since Wehrspann Reservoir ices over in the winter and based on the occurrence of thermal stratification in the summer it appears to fit the definition of a discontinuous cold polymictic to a dimictic lake (Wetzel, 2001).

6.1.5.2.1.3 Dissolved Oxygen Conditions

6.1.5.2.1.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Wehrspann Reservoir based on depth-profile measurements taken during 2009 and 2010. Plates 60 and 61, respectively, provide longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September in 2009 and 2010. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored near the reservoir bottom during the summer of both years (Plates 60 and 61).

6.1.5.2.1.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

The depth-profile dissolved oxygen measurements collected during the summer over the past 5 years at the deep water area near the dam were compiled and plotted to describe the existing summer dissolved oxygen conditions of Wehrspann Reservoir (Plate 62). Several of the plotted profiles indicate a significant vertical gradient in dissolved oxygen levels tending towards a clinograde distribution. Some profiles show a fairly constant dissolved oxygen concentration from the reservoir surface to the bottom. These profiles were measured in early spring or late summer and are believed to be a result of thermal stratification breaking down and the water column mixing as “turnover” of the reservoir occurred.

6.1.5.2.1.3.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of Wehrspann Reservoir with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2009 and 2010 and the District’s current Area-Capacity Tables for the reservoir. The constructed contour plots were reviewed to identify the “worst-case” dissolved oxygen condition. The “worst-case” condition was taken to be the contour plot with the highest elevations of the 5 mg/l and 2.5 mg/l dissolved oxygen isopleths. The July 6, 2009

contour plot indicates a pool elevation of 1095.9 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1087.5 ft msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1086.0 ft-msl (Plate 60). The current District Area-Capacity Tables (2009 Survey) give storage capacities of 2,326 ac-ft for elevation 1095.9 ft-msl, 763 ac-ft for elevation 1087.5 ft-msl, and 583 ac-ft for elevation 1086.0 ft-msl. On July 6, 2009 it is estimated that 33 percent of the volume of Wehrspann Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 25 percent of the reservoir volume was hypoxic.

6.1.5.2.1.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in Wehrspann Reservoir indicated hypoxic conditions were prevalent during the summers of 2009 and 2010, longitudinal contour and depth-profile plots were constructed for ORP and pH. Near-surface and near-bottom water quality samples collected when hypoxia was present were also compared.

6.1.5.2.1.4.1 <u>Oxidation-Reduction Potential</u>

Plates 63 and 64, respectively, provide longitudinal ORP contour plots based on measurements taken in 2009 and 2010. The ORP values measured in mid-summer indicate somewhat reduced conditions present near the bottom of Wehrspann Reservoir in 2009, and more strongly reduced conditions present in 2010 (Plates 63 and 64). Plate 65 plots depth profiles for ORP measured during the summer over the past 5 years in the deep water area of Wehrspann Reservoir near the dam. A vertical gradient in ORP occasionally occurred in the reservoir during the summer, especially near the bottom (Plate 65).

6.1.5.2.1.4.2 <u>pH</u>

Longitudinal contour plots for pH conditions measured in 2009 and 2010 are provided, respectively, in Plates 66 and 67. Occasional reduced conditions in the deeper water of Wehrspann Reservoir seemingly lead to in lower pH levels near the reservoir bottom (Plates 66 and 67). The lowest measured pH levels near the reservoir bottom were above the lower pH criterion of 6.5 for the protection of warmwater aquatic life. On August 10, 2010 the highest measured pH values were above the the upper pH criterion of 9.0 for the protection of warmwater aquatic life (Plate 67). Plate 62 plots depth profiles for pH measured during the summer over the past 5 years in the deep water area of Wehrspann Reservoir near the dam. An appreciable vertical gradient in pH occurred in the reservoir during the summer (Plate 68).

6.1.5.2.1.4.3 <u>Comparison of Near-Surface and Near-Bottom Water Quality Conditions</u>

Paired near-surface and near-bottom water quality samples collected from Wehrspann Reservoir during the summer when hypoxia was present were compared. Near-surface conditions were represented by samples collected within 1-meter of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site WEHLKND1 during the 5-year period 2006 through 2010. During the 5-year period a total of 25 paired samples were collected monthly from May through September. Of the 25 paired samples collected, 14 (56%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature (14), dissolved oxygen (14), oxidation-reduction potential (14), pH (14), alkalinity (14), total ammonia (14), nitrate-nitrate nitrogen (14), total phosphorus (14), and orthophosphorus (14) (Plate 69) *[Note: the number in parentheses is the number of paired observations available for each parameter]*. A paired

two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were not significantly different for total ammonia nitrogen, nitrate-nitrite nitrogen, total alkalinity, or total phosphorus. Parameters that were significantly lower in the near-bottom water of Wehrspann Reservoir when hypoxia was present included: water temperature ($p < 0.0001$), dissolved oxygen ($p < 0.0001$), ORP ($p < 0.01$), and pH ($p < 0.0001$). Parameters that were significantly higher in the near-bottom water included: total phosphorus ($p < 0.05$), ortho-phosphorus ($p < 0.05$), and total ammonia ($p < 0.05$).

6.1.5.2.1.5 Water Clarity

6.1.5.2.1.5.1 <u>Secchi Transparency</u>

Figure 6.13 displays a box plot of the Secchi depth transparencies measured at sites WEHLKND1, WEHLKML1, and WEHLKUP1 from 2008 to 2010 (note: the monitoring sites are oriented in an upstream to downstream direction). The Secchi depth transparencies measured at sites WEHLKND1 and WEHLKML1 were similar and greater than transparencies measured at site WEHLKUP1.

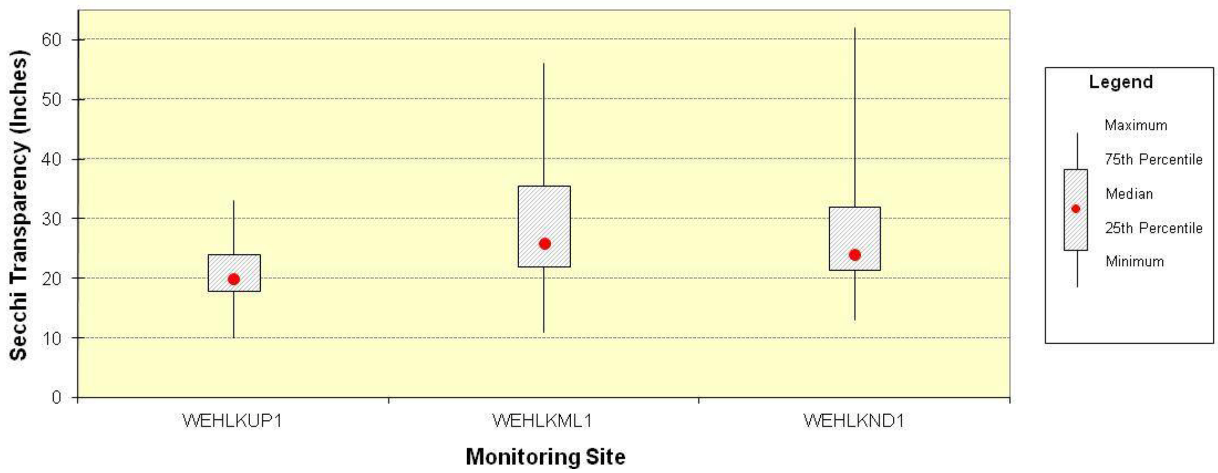

Figure 6.13. Box plot of Secchi depth transparencies measured in Wehrspann Reservoir from 2008 to 2010. (Note: monitoring sites are oriented on the x-axis in an upstream to downstream direction.)

6.1.5.2.1.5.2 <u>Turbidity</u>

Turbidity contour plots were constructed along the length of Wehrspann Reservoir based on depth-profile measurements taken during 2009 and 2010. Plates 70 and 71, respectively, provide longitudinal turbidity contour plots based on depth-profile measurements taken from May through September. Turbidity levels in Wehrspann Reservoir vary longitudinally from the dam to reservoir's upper reaches, with turbidity levels being higher in the upper reaches of the reservoir (Plate 71). Some vertical variation in turbidity also occurs (Plate 70).

6.1.5.2.1.6 Reservoir Trophic Status

Trophic State Index (TSI) values for Wehrspann Reservoir were calculated from monitoring data collected during the 5-year period 2006 through 2010 at the near-dam ambient monitoring site (i.e., WEHLKND1). Table 6.6 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Wehrspann Reservoir is in a hypereutrophic condition.

Table 6.6. Summary of Trophic State Index (TSI) values calculated for Wehrspann Reservoir for the 5-year period 2006 through 2010.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	25	66	67	53	76
TSI(TP)	25	62	63	48	71
TSI(Chl)	25	72	74	40	87
TSI(Avg)	25	67	67	54	76

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values for the individual parameters.
Note: See Section 4.1.3 for discussion of TSI calculation.

6.1.5.2.2 Water Quality Trends (1986 through 2008)

Water quality trends from 1986 to 2010 were determined for Wehrspann Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through October at the near-dam monitoring site (i.e., WEHLKND1). Plate 72 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, it appears that Wehrspann Reservoir exhibited decreasing transparency, slightly decreasing total phosphorus concentrations, and increasing chlorophyll *a* levels (Plate 72). Over the 31-year period since 1980, Wehrspann Reservoir has moved from a eutrophic to hypereutrophic condition (Plate 72).

6.1.5.3 <u>Existing Water Quality Conditions of Runoff Inflows to Wehrspann Reservoir</u>

6.1.5.3.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Existing water quality conditions in the main tributary inflow to Wehrspann Reservoir was monitored under runoff conditions, during the period of April through September, at two sites WEHNFUSB1 and WEHNFDSB1 (Figure 6.12). Site WEHNFUSB1 was about 1½ miles above the constructed sediment basin/wetland and site WEHNFDSB1 was at the sediment basin/wetland outflow. Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from “base-flow” conditions. Plates 73 and 74, respectively, summarize water quality conditions that were monitored at sites WEHNFUSB1 and WEHNFDSB1 under runoff conditions during the period 2006 through 2010.

6.1.5.3.2 Impact of Constructed Sediment Basin/Wetland on Water Quality Conditions of Runoff Inflow

Runoff water quality conditions monitored upstream and downstream of the constructed sediment basin/wetland over the 7-year period 2004 through 2010 were compared. Paired runoff samples collected at sites WEHNFUSB1 (i.e., upstream) and WEHNFDSB1 (i.e., downstream) were compared for the following parameters: turbidity, total suspended solids, total phosphorus, total Kjeldahl nitrogen, total ammonia nitrogen, nitrate-nitrite nitrogen, atrazine, metolachlor, and alachlor. Box plots were constructed for each parameter to display the distribution of the paired runoff samples collected upstream and downstream of the constructed sediment basin/wetland (Plate 75). A paired two-tailed t-test was used to determine if the sampled upstream and downstream runoff conditions were significantly different. The sampled paired runoff conditions upstream and downstream of the constructed sediment basin/wetland were not significantly different ($\alpha = 0.05$) for total ammonia nitrogen, atrazine, alachlor, and metolachlor.

Parameters that were significantly lower downstream of the constructed sediment basin wetland included: turbidity ($p < 0.01$), total suspended solids ($p < 0.001$), total Kjeldahl nitrogen ($p < 0.0001$), nitrate-nitrite nitrogen ($p < 0.05$), and total phosphorus ($p < 0.0001$). Measured runoff levels of atrazine and metolachlor upstream of the constructed sediment basin/wetland noticeably spiked in the spring, seemingly after recent applications of the herbicides.

6.2 SALT CREEK WATERSHED PROJECTS

6.2.1 BACKGROUND INFORMATION

6.2.1.1 Salt Creek Watershed Hydrology

Streamflow in the Salt Creek watershed follows a characteristic pattern. Flows are generally low except for brief periods of rise caused by runoff from rainfall events. A snowpack over the basin in early spring can produce a significant rise in flow as a result of snowmelt runoff. Streams in the basin generally freeze over during the winter months.

6.2.1.2 Tributary Project Reservoirs

Ten Tributary Projects [Bluestem, Branched Oak, Conestoga, Holmes, Olive Creek, Pawnee, Stagecoach, Twin Lakes (East and West Twin Reservoirs), Wagon Train, and Yankee Hill are located in the Salt Creek watershed in southeast Nebraska in the vicinity of the City of Lincoln (Figure 6.14). The authorized purposes for all the reservoirs are flood control, recreation, and fish and wildlife management. Table 6.7 gives selected engineering data for the Salt Creek Tributary Project reservoirs. Lake restoration projects have recently been completed on Holmes and Yankee Hill Reservoirs.

6.2.1.3 Water Quality Standards Classifications and Section 303(d) Listings

The State of Nebraska's water quality standards designates the following beneficial uses to all the Salt Creek Tributary Project reservoirs: recreation, warmwater aquatic life, agricultural water supply, and aesthetics. None of the reservoirs are used as a public drinking water supply. Designated swimming beaches are present at Branched Oak, Pawnee, Bluestem, and Wagon Train Reservoirs. The State's water quality standards identify nutrient criteria for lakes and impounded waters based on the categorization of the physical, chemical, and biological characteristics of the waterbody. Under this categorization Bluestem, Branched Oak, Conestoga, East Twin, Olive Creek, Pawnee, Stagecoach, Wagon Train, and Yankee Hill Reservoirs have been included in a common group coded as R13 impounded waters. Holmes and West Twin Reservoirs, respectively, have been included in other groupings coded as R14 and R18 impounded waters.

Pursuant to the Federal CWA, the State of Nebraska has listed several of the Salt Creek reservoirs as "Category 5" waters on the State's 2010 Section 303(d) list (see Table 1.3). A "Category 5" listing infers that at least one beneficial use is impaired and a TMDL is required. Salt Creek reservoirs listed as "Category 5" waters include: Bluestem, Branched Oak, Conestoga, East Twin, Olive Creek, Pawnee, Stagecoach, Wagon Train, and West Twin. The beneficial uses impaired include aquatic life, aesthetics, and recreation. The identified pollutants/stressors include: algae toxins, ammonia, arsenic, nutrients, and sediment. TMDLs have been completed for Holmes, Pawnee, Wagon Train, and Yankee Hill Reservoirs.

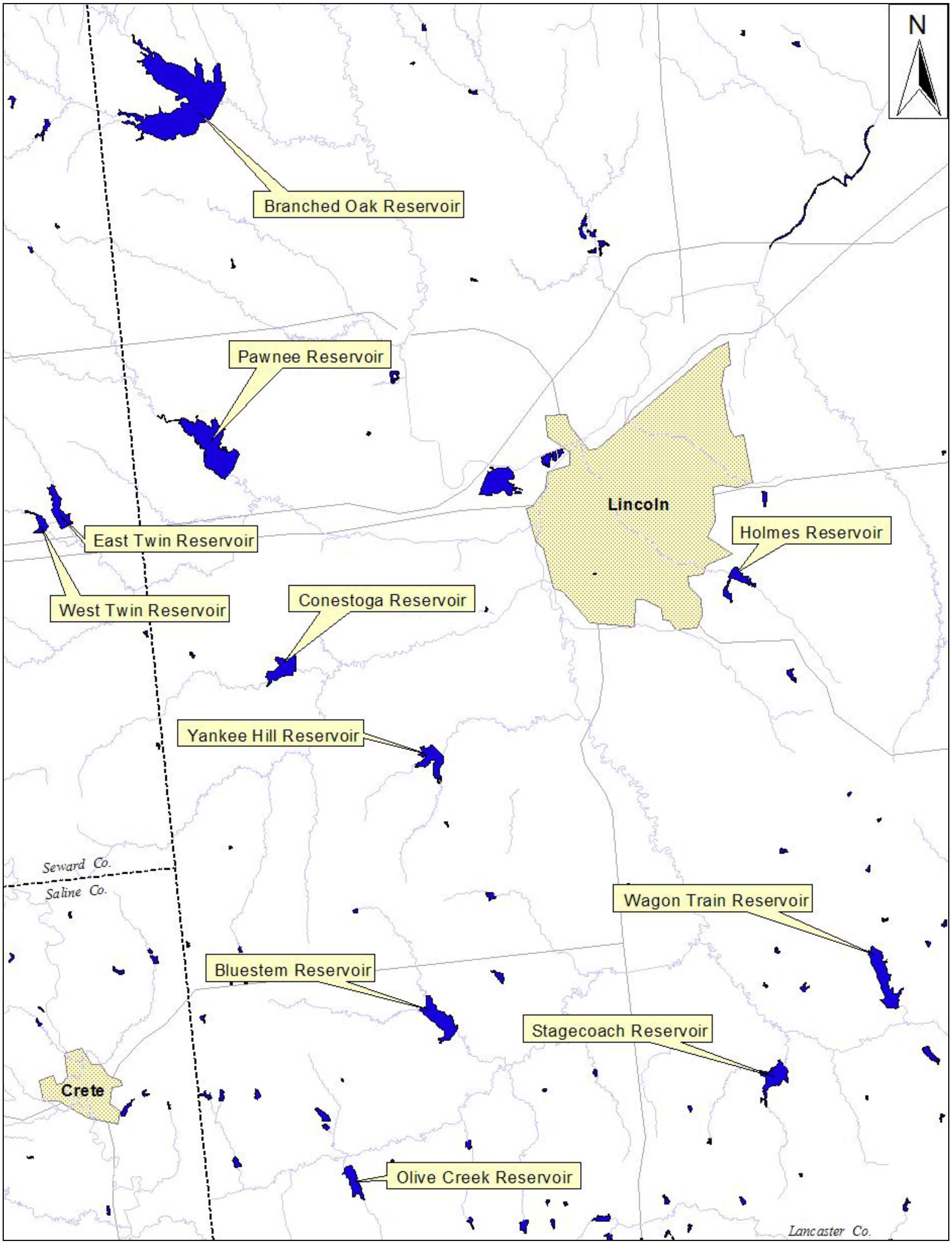

Figure 6.14. Location of the Salt Creek Tributary Project reservoirs in southeast Nebraska.

Table 6.7. Summary of selected engineering for the Salt Creek Tributary Projects.

	Bluestem Reservoir (Dam Site No. 4)		Branched Oak Reservoir (Dam Site No. 18)		Conestoga Reservoir (Dam Site No. 12)		Holmes Reservoir (Dam Site No. 17)	
General								
Dammed Stream	N. Trib. of Olive Branch		Oak Creek		Holmes Creek		Antelope Creek	
Drainage Area	16.6 sq. mi.		89.0 sq. mi.		15.1 sq. mi.		5.4 sq. mi.	
Reservoir Length [(1)]	1.6 miles		3.7 miles		1.4 miles		0.7 miles	
Conservation Pool Elevation (Top)	1307.4 ft-msl		1284.0 ft-msl		1232.9 ft-msl		1242.4 ft-msl	
Date of Dam Closure	12 September 1962		21 August 1967		24 September 1963		17 September 1962	
Date of Initial Fill[(2)]	6 July 1963		18 January 1973		May 1965		2 June 1965	
"As-Built" Conditions[(3)]	(1964)		(1967)		(1964)		(1963)	
Lowest Reservoir Bottom Elevation	1281 ft-msl		1244 ft-msl		1207 ft-msl		1224 ft-msl	
Surface Area at top of Conservation Pool	316 ac		1,798 ac		227 ac		123 ac	
Capacity to top of Conservation Pool	3,057 ac-ft		26,385 ac-ft		2,472 ac-ft		1,059 ac-ft	
Mean Depth at top of Conservation Pool[(4)]	9.7 ft		14.7 ft		10.9 ft		8.6 ft	
Surveyed Conditions	(1993:USACE)	(2002:USGS)	(1991:USACE)	(2003:NGPC)	(1996:USACE)	(2002:USGS)	(1993:USACE)	(2006:NGPC)
Lowest Reservoir Bottom Elevation	1288 ft-msl	1291 ft-msl	1252 ft-msl	1252 ft-msl	1216 ft-msl	1214 ft-msl	1228 ft-msl	1226 ft-msl
Surface Area at top of Conservation Pool	309 ac	290 ac	1,847 ac	1,761 ac	217 ac	211 ac	123 ac	108 ac
Capacity to top of Conservation Pool	2,531 ac-ft	2,102 ac-ft	25,088 ac-ft	24,526 ac-ft	1,808 ac-ft	1,846 ac-ft	783 ac-ft	931 ac-ft
Mean Depth at top of Conservation Pool[(4)]	8.2 ft	7.2 ft	13.6 ft	13.9 ft	8.3 ft	8.7 ft	6.4 ft	8.6 ft
Sediment Deposition in Conservation and Sediment Pools	(1993:USACE)	(2002:USGS)	(1991:USACE)	(2003:NGPC)	(1996:USACE)	(2002:USGS)	(1993:USACE)	(2006:NGPC)
Surveyed Sediment Deposition[(5)]	526 ac-ft	955 ac-ft	1,297 ac-ft	1,859 ac-ft	664 ac-ft	626 sc-ft	276 ac-ft	128 ac-ft
Annual Sedimentation Rate[(6)]	17.5 ac-ft/yr	24.5 ac-ft/yr	51.9 ac-ft/yr	50.2 ac-ft/yr	20.1 ac-ft/yr	16.1 ac-ft/yr	8.9 ac-ft/yr	-----
Current Estimated Sediment Deposition[(7)]	824 ac-ft	1,151 ac-ft	2,283 ac-ft	2,210 ac-ft	945 ac-ft	754 ac-ft	-----	173 ac-ft[(9)]
Current capacity to top of Conservation Pool[(8)]	2,233 ac-ft	1,906 ac-ft	24,102 ac-ft	24,174 ac-ft	1,527 ac-ft	1,718 ac-ft	-----	886ac-ft[(9)]
Percent of "As-Built" capacity to top of the Conservation Pool lost to current estimated sediment deposition	27%	38%	9%	8%	38%	31%	-----	16%[(9)]
Operational Details – Historic	(1964 – 2010)		(1973-2010)		(1966 – 2010)		(1966 – 2010)	
Maximum Recorded Pool Elevation	1316.5 ft-msl	11-Oct-73	1287.9 ft-msl	26-Aug-87	1241.1 ft-msl	24-Mar-87	1250.0 ft-msl	24-Jul-93
Minimum Recorded Pool Elevation	1299.1 ft-msl	28-Oct-91	1274.7 ft-msl	2-Apr-70	1224.9 ft-msl	22-Apr-07	1224.9 ft-msl[(10)]	22-Apr-07
Maximum Recorded Daily Inflow	1,447 cfs	10-Oct-73	3,700 cfs	25-Aug-87	907 cfs	23-Mar-87	604 cfs	24-Jul-93
Maximum Recorded Daily Outflow	342 cfs	12-Oct-73	774 cfs	25-Jul-93	185 cfs	25-Mar-87	187 cfs	29-Jun-83
Average Annual Pool Elevation	1305.8 ft-msl		1282.8 ft-msl		1232.0 ft-msl		1240.7 ft-msl	
Average Annual Inflow	4,461 ac-ft		25,067 ac-ft		4,524 ac-ft		3,175 ac-ft	
Average Annual Outflow	3,329 ac-ft		19,097 ac-ft		3,787 ac-ft		2,757 ac-ft	
Estimated Retention Time[(11)]	0.67 Years		1.26 Years		0.40 Years		0.32 Years	
Operational Details – Current[(12)]								
Maximum Recorded Pool Elevation	1309.2 ft-msl	22-Jun-10	1286.2 ft-msl	22-Jun-10	1235.8 ft-msl	21-Jun-10	1246.5 ft-msl	21-Jun-10
Minimum Recorded Pool Elevation	1305.0ft-msl	13-Oct-09	1283.7 ft-msl	13-Oct-09	1232.3 ft-msl	12-Oct-09	1242.0 ft-msl	05-Oct-09
Maximum Recorded Daily Inflow	202 cfs	20-Jun-10	1,371 cfs	21-Jun-10	236 cfs	21-Jun-10	174 cfs	21-Jun-10
Maximum Recorded Daily Outflow	48 cfs	21-Jun-10	228 cfs	23-Jun-10	62 cfs	22-Jun-10	58 cfs	22-Jun-10
Total Inflow (% of Average Annual)	4,683 ac-ft	(103%)	27,941 ac-ft	(109%)	4,080 ac-ft	(88%)	3,953 ac-ft	(121%)
Total Outflow (% of Average Annual)	3,220 ac-ft	(94%)	22,596 ac-ft	(115%)	3,299 ac-ft	(85%)	4,619 ac-ft	(165%)
Outlet Works								
Ungated Outlets	2) 30" x 96" 2) 12" x 54"	1313.5 ft-msl 1307.4 ft-msl	2) 42" x 144"	1284.0 ft-msl	2) 30" x 96" 2) 12" x 54"	1242.3 ft-msl 1232.9 ft-msl	2) 30" x 96" 2) 12" x 36"	1249.0 ft-msl 1242.5 ft-msl
Gated Outlets (Low-level)	1) 36" x 36"	1303.0 ft-msl	1) 48" x 72" 1) 10" Dia.	1274.0 ft-msl 1276.3 ft-msl	1) 36" x 36"	1228.0 ft-msl	1) 36" x 36" 1) 45" x 45"	1239.0 ft-msl 1230.6 ft-msl[(13)]

(1) Reservoir length at top of Conservation Pool.
(2) First occurrence of reservoir pool elevation to top of Conservation Pool elevation.
(3) "As-Built" conditions taken to be the conditions present when the reservoir was first surveyed.
(4) Mean Depth = Volume ÷ Surface Area.
(5) Surveyed sediment deposition is the difference in reservoir storage capacity to top of Conservation Pool between "as-built" and survey.
(6) Annualized sedimentation rate based on historic sediment deposition.
(7) Current estimated sediment deposition is based on the historic sediment deposition and the annual sedimentation rate over the number of years since the latest survey.
(8) Current capacity of Multipurpose Pool = "As-Built" Multipurpose Pool capacity - Estimated Current Sedimentation.
(9) A lake renovation project was completed at Holmes Reservoir in 2005 and an estimated 200 ac-ft of sediment was removed from the bottom of the reservoir. Holmes Reservoir was surveyed by NGPC in 2006. Values given are estimates for conditions after the removal of the sediment based on the NGPC survey.
(10) Reservoir drawn down for lake renovation project.
(11) Estimated Retention Time = Multipurpose Pool Volume ÷ Average Annual Outflow.
(12) Current operational details are for the water year 1-Oct-2009 through 30-Sep-2010.
(13) A new gate was installed in the Holmes Dam outlet works as part of the 2004 Lake renovation Project to allow the reservoir to be drawn down to lower pool elevations.

Table 6.7. (Continued).

	Olive Creek Reservoir (Dam Site No. 2)		Pawnee Reservoir (Dam Site No. 14)		Stagecoach Reservoir (Dam Site No. 9)		Twin Lakes East and West Twin Res. (Dam Site No. 13)	
General								
Dammed Stream	S. Trib of Olive Branch		North Middle Creek		S. Trib. Of Hickman Branch		Middle Creek	
Drainage Area	8.2 sq. mi.		35.9 sq. mi.		9.7 sq. mi.		11.0 sq. mi.	
Reservoir Length[1]	1.2 miles		3.0 miles		1.4 miles		1.5 miles	
Conservation Pool Elevation (Top)	1335.0 ft-msl		1244.3 ft-msl		1271.1 ft-msl		1341.0 ft-msl	
Date of Dam Closure	20 September 1963		16 July 1964		27 August 1963		26 September 1965	
Date of Initial Fill[2]	30 June 1965		21 June 1967		May 1965		18 March 1969	
"As-Built" Conditions[3]	(1964)		(1966)		(1964)		(1966)	
Lowest Reservoir Bottom Elevation	1316 ft-msl		1209 ft-msl		1252 ft-msl		1316 ft-msl	
Surface Area at top of Conservation Pool	169 ac		734 ac		201 ac		245 ac	
Capacity to top of Conservation Pool	1,298 ac-ft		8,695 ac-ft		1,770 ac-ft		2,561 ac-ft	
Mean Depth at top of Conservation Pool[4]	7.7 ft		11.8 ft		8.8 ft		10.5 ft	
Latest Surveyed Conditions	(1993:USACE)	(2005:USGS)	(1991:USACE)	(2002:NGPC)	(1990:USACE)	(2002:USGS)	(1994:USACE)	(2002:USGS)
Lowest Reservoir Bottom Elevation	1322 ft-msl	1320 ft-msl	1219 ft-msl	1220 ft-msl	1256 ft-msl	1256 ft-msl	1320 ft-msl	1320 ft-msl
Surface Area at top of Conservation Pool	162 ac	120 ac	725 ac	604 ac	195 ac	196 ac	236 ac	232 ac
Capacity to top of Conservation Pool	1,100 ac-ft	1,060 ac-ft	7,500 ac-ft	6,924 ac-ft	1,451 ac-ft	1,422 ac-ft	2,161 ac-ft	1,808 ac-ft
Mean Depth at top of Conservation Pool[4]	6.8 ft	8.8 ft	10.3 ft	11.5 ft	7.4 ft	7.3 ft	9.2 ft	7.8 ft
Sediment Deposition in Conservation and Sediment Pools	(1993:USACE)	(2005:USGS)	(1991:USACE)	(2002:NGPC)	(1990:USACE)	(2002:USGS)	(1994:USACE)	(2002:USGS)
Surveyed Sediment Deposition[5]	198 ac-ft	238 ac-ft	1,195 ac-ft	1,771 ac-ft	319 ac-ft	348 ac-ft	400 ac-ft	753 ac-ft
Annual Sedimentation Rate[6]	6.6 ac-ft/yr	-----[9]	46.0 ac-ft/yr	47.9 ac-ft/yr	11.8 ac-ft/yr	8.9 ac-ft/yr	13.8 ac-ft/yr	20.4 ac-ft/yr
Current Estimated Sediment Deposition[7]	225 ac-ft[9]	271[9]	2,068 ac-ft	2,154 ac-ft	556 ac-ft	420 ac-ft	621ac-ft	916 ac-ft
Current capacity to top of Conservation Pool[8]	1,073 ac-ft[9]	1,027 ac-ft[9]	6,627ac-ft	6,541 ac-ft	1,214 ac-ft	1,350 ac-ft	1,940 ac-ft	1,645 ac-ft
Percent of "As-Built" capacity to top of the Conservation Pool lost to current estimated sediment deposition	17%[9]	21%[9]	24%	25%	30%	24%	24%	36%
Operational Details – Historic	(1966 – 2010)		(1968 – 2010)		(1965 – 2010)		(1969 – 2010)	
Maximum Recorded Pool Elevation	1342.6 ft-msl	24-Jul-93	1249.1 ft-msl	25-Jul-93	1279.7 ft-msl	5-Jun-08	1346.9 ft-msl	29-Jun-83
Minimum Recorded Pool Elevation	1324.3 ft-msl[10]	1-Dec-99	1236.6 ft-msl	15-Nov-66	1259.6 ft-msl	31-Oct-91	1332.1 ft-msl	31-Oct-91
Maximum Recorded Daily Inflow	920 cfs	23-May-04	1,381 cfs	24-Mar-87	1,030 cfs	23-May-04	632 cfs	13-Jul-93
Maximum Recorded Daily Outflow	188 cfs	24-May-04	420 cfs	25-Jul-93	193 cfs	6-Jun-08	168 cfs	30-Jun-83
Average Annual Pool Elevation	1332.1 ft-msl		1243.5 ft-msl		1270.2 ft-msl		1339.3 ft-msl	
Average Annual Inflow	2,194 ac-ft		6,893 ac-ft		3,197 ac-ft		3,550 ac-ft	
Average Annual Outflow	1,636 ac-ft		4,479 ac-ft		2,535 ac-ft		2,741 ac-ft	
Estimated Retention Time[11]	0.66 Years		1.48 Years		0.48 Years		0.71 Years	
Operational Details – Current[12]								
Maximum Recorded Pool Elevation	1336.0 ft-msl	21-Jun-10	1245.7 ft-msl	21-Jun-10	1272.7 ft-msl	12-Mar-10	1343.7 ft-msl	21-Jun-10
Minimum Recorded Pool Elevation	1331.5 ft-msl	20-Oct-09	1243.5ft-msl	05-Oct-09	1270.7 ft-msl	05-Oct-09	1340.4 ft-msl	19-Oct-09
Maximum Recorded Daily Inflow	71 cfs	21-Jun-10	494 cfs	21-Jun-10	79 cfs	07-Mar-10	359 cfs	21-Jun-10
Maximum Recorded Daily Outflow	16 cfs	21-Jun-10	100 cfs	21-Jun-10	23 cfs	12-Mar-10	150 cfs	22-Jun-10
Total Inflow (% of Average Annual)	1,371 ac-ft	(61%)	5,488 ac-ft	(78%)	3,332ac-ft	(102%)	4,320 ac-ft	(118%)
Total Outflow (% of Average Annual)	432 ac-ft	(26%)	3,002 ac-ft	(66%)	2,744 ac-ft	(106%)	3,497 ac-ft	(124%)
Outlet Works								
Ungated Outlets	2) 24" x 72" 2) 12" x 30"	1340.9 ft-msl 1335.0 ft-msl	2) 34" x 120"	1244.3 ft-msl	2) 24" x 72" 2) 12" x 30"	1277.1 ft-msl 1271.1 ft-msl	2) 24" x 63"	1341.0 ft-msl
Gated Outlets (Low-level)	1) 36" x 36"	1330.0 ft-msl	1) 42" x 60"	1236.0 ft-msl	1) 36" x 36"	1261.0 ft-msl	1) 42" x 54"	1333.0 ft-msl

(1) Reservoir length at top of Conservation Pool.
(2) First occurrence of reservoir pool elevation to top of Conservation Pool elevation.
(3) "As-Built" conditions taken to be the conditions present when the reservoir was first surveyed.
(4) Mean Depth = Volume ÷ Surface Area.
(5) Surveyed sediment deposition is the difference in reservoir storage capacity to top of Conservation Pool between "as-built" and survey.
(6) Annualized sedimentation rate based on historic sediment deposition.
(7) Current estimated sediment deposition is based on the historic sediment deposition and the annual sedimentation rate over the number of years since the latest survey.
(8) Current capacity of Multipurpose Pool = "As-Built" Multipurpose Pool capacity - Estimated Current Sedimentation.
(9) A lake renovation project was completed at Olive Creek Reservoir in 2000 and an estimated 85 ac-ft of sediment was removed from the bottom of the reservoir. Values given are estimates for conditions after the removal of the sediment. The USGS 2005 survey was conducted after the lake renovation project was completed.
(10) Reservoir drawn down for lake renovation project.
(11) Estimated Retention Time = Multipurpose Pool Volume ÷ Average Annual Outflow.
(12) Current operational details are for the water year 1-Oct-2009 through 30-Sep-2010.

Table 6.7. (Continued).

	Wagon Train Reservoir (Dam Site No. 8)		Yankee Hill Reservoir (Dam Site No. 10)			
General						
Dammed Stream	N. Trib. Of Hickman Branch		Cardwell Branch			
Drainage Area	15.6 sq. mi.		9.7 sq. mi.			
Reservoir Length[(1)]	1.8 miles		1.4 miles			
Conservation Pool Elevation (Top)	1287.8 ft-msl		1244.9 ft-msl			
Date of Dam Closure	24 September 1962		27 August 1963			
Date of Initial Fill[(2)]	24 June 1963		May 1965			
"As-Built" Conditions[(3)]	(1963)		(1966)			
Lowest Reservoir Bottom Elevation	1261 ft-msl		1226 ft-msl			
Surface Area at top of Conservation Pool	279 ac		216 ac			
Capacity to top of Conservation Pool	2,272 ac-ft		1,907 ac-ft			
Mean Depth at top of Conservation Pool[(4)]	8.1 ft		8.8 ft			
Latest Surveyed Conditions	(1993:USACE)	(2005:USGS)	(1994:USACE)	(2005:USGS)		
Lowest Reservoir Bottom Elevation	1272 ft-msl	1273 ft-msl	1231 ft-msl	1228 ft-msl		
Surface Area at top of Conservation Pool	277 ac	293 ac	211 ac	192 ac		
Capacity to top of Conservation Pool	2,053 ac-ft	2,012 ac-ft	1,627 ac-ft	1,680		
Mean Depth at top of Conservation Pool[(4)]	7.4 ft	6.9 ft	7.7 ft	8.8 ft		
Sediment Deposition in Conservation and Sediment Pools	(1993:USACE)	(2005:USGS)	(1994:USACE)	(2005:USGS)		
Surveyed Sediment Deposition[(5)]	219 ac-ft	260 ac-ft	280 ac-ft	227 ac-ft		
Annual Sedimentation Rate[(6)]	7.1 ac-ft/yr	-----[(8)]	9.7 ac-ft/yr	-----[(9)]		
Current Estimated Sediment Deposition[(7)]	294 ac-ft[(8)]	309 ac-ft[(8)]	217 ac-ft[(9)]	285ac-ft[(9)]		
Current capacity to top of Conservation Pool[(10)]	1,978 ac-ft[(8)]	1,963 ac-ft[(8)]	1,690ac-ft[(9)]	1,621 ac-ft[(9)]		
Percent of "As-Built" capacity to top of the Conservation Pool lost to current estimated sediment deposition	13%[(8)]	14%	11%[(9)]	15%		
Operational Details – Historic	(1964 – 2010)		(1968 – 2010)			
Maximum Recorded Pool Elevation	1295.5 ft-msl	5-Jun-08	1252.3 ft-msl	11-Oct-73		
Minimum Recorded Pool Elevation	1273.1 ft-msl[(11)]	5-Apr-00	1232.0 ft-msl[(11)]	2004-2006		
Maximum Recorded Daily Inflow	1,199 cfs	10-Oct-73	690 cfs	10-Oct-73		
Maximum Recorded Daily Outflow	334 cfs	25-Jul-93	145 cfs	12-Oct-73		
Average Annual Pool Elevation	1286.3 ft-msl		1242.9 ft-msl			
Average Annual Inflow	5,209 ac-ft		4,773 ac-ft			
Average Annual Outflow	4,256 ac-ft		4,099 ac-ft			
Estimated Retention Time[(12)]	0.46 Years		0.41 Years			
Operational Details – Current[(13)]						
Maximum Recorded Pool Elevation	1291.1 ft-msl	21-Jun-10	1247.6 ft-msl	21-Jun-10		
Minimum Recorded Pool Elevation	1287.5 ft-msl	13-Oct-09	1243.6 ft-msl	20-Oct-09		
Maximum Recorded Daily Inflow	433 cfs	21-Jun-10	187 cfs	21-Jun-10		
Maximum Recorded Daily Outflow	79 cfs	22-Jun-10	35 cfs	23-Jun-10		
Total Inflow (% of Average Annual)	15,632 ac-ft	(299%)	5,036 ac-ft	(103%)		
Total Outflow (% of Average Annual)	14,703 ac-ft	(344%)	4,245 ac-ft	(101%)		
Outlet Works						
Ungated Outlets	2) 30" x 96" 2) 12" x 54"	1292.4 ft-msl 1287.8 ft-msl	2) 18" x 63" 2) 12" x 30"	1250.0 ft-msl 1244.9 ft-msl		
Gated Outlets (Low-level)	1) 36" x 36"	1283.5 ft-msl	1) 36" x 36"	1237.0 ft-msl		

(1) Reservoir length at top of Conservation Pool.
(2) First occurrence of reservoir pool elevation to top of Conservation Pool elevation.
(3) "As-Built" conditions taken to be the conditions present when the reservoir was first surveyed.
(4) Mean Depth = Volume ÷ Surface Area.
(5) Surveyed sediment deposition is the difference in reservoir storage capacity to top of Conservation Pool between "as-built" and survey.
(6) Annualized sedimentation rate based on historic sediment deposition.
(7) Current estimated sediment deposition is based on the historic sediment deposition and the annual sedimentation rate over the number of years since the latest survey.
(8) A lake renovation project was completed at Wagon Train Reservoir in 2003 and an estimated 45 ac-ft of sediment was removed from the bottom of the reservoir. Values given are estimates for conditions after the removal of the sediment. The USGS 2005 survey was conducted after the lake renovation project was completed.
(9) A lake renovation project was completed at Yankee Hill Reservoir in 2005 and an estimated 217 ac-ft of sediment was removed from the bottom of the reservoir. From 1966 to 2003 an estimated 367 ac-ft (280 ac-ft + 9 x 9.7 ac-ft/yr) of sediment was deposited in Yankee Hill Reservoir. After the lake renovation project, it is estimated that the accumulated sediment in Yankee Hill Reservoir was 150 ac-ft (i.e., 367 - 217 ac-ft). The USGS 2005 survey was conducted after the lake renovation project was completed.
(10) Current capacity of Multipurpose Pool = "As-Built" Multipurpose Pool capacity - Estimated Current Sedimentation.
(11) Reservoir drawn down for lake renovation project..
(12) Estimated Retention Time = Multipurpose Pool Volume ÷ Average Annual Outflow.
(13) Current operational details are for the water year 1-Oct-2009 through 30-Sep-2010.

6.2.2 BLUESTEM RESERVOIR

6.2.2.1 Background Information

6.2.2.1.1 Project Overview

The dam forming Bluestem Reservoir is located on a tributary to the Olive Branch. The dam was completed on September 12, 1962 and the reservoir reached its initial fill on July 6, 1963. The Bluestem Reservoir watershed is 16.6 square miles. The watershed was largely agricultural when the dam was built in 1962 and has remained so to the present time.

6.2.2.1.2 Bluestem Dam Intake Structure

The intake structure at Bluestem Dam is a single reinforced concrete box shaft commonly called a two-way drop inlet. Its inside dimensions are 5 feet by 8 feet. The intake structure has four ungated openings – two 30" x 96" openings with a crest elevation at 1313.5 ft-msl and two 12" x 54" openings with a crest elevation of 1307.4. A 36" x 36" gated opening with a crest elevation at 1303.0 ft-msl was constructed into the upstream wall. The purpose of the gated opening is to lower the level of the conservation pool in order to inspect the conduit, make shoreline repairs, and manage fish populations. It may also be used to release water for downstream needs when the reservoir is below conservation pool.

6.2.2.1.3 Reservoir Storage Zones

Figure 6.15 depicts the current storage zones of Bluestem Reservoir based on the 1993 survey data and estimated sedimentation. It is estimated that 27 to 38 percent of the "as-built" volume to the top of the Conservation Pool has been lost to sedimentation as of 2010. The annual volume loss is estimated to be 0.57 to 0.80 percent. Based on the State of Nebraska's impairment assessment methodology, these values indicate that Bluestem Reservoir's water quality dependent uses are impaired due to sedimentation.

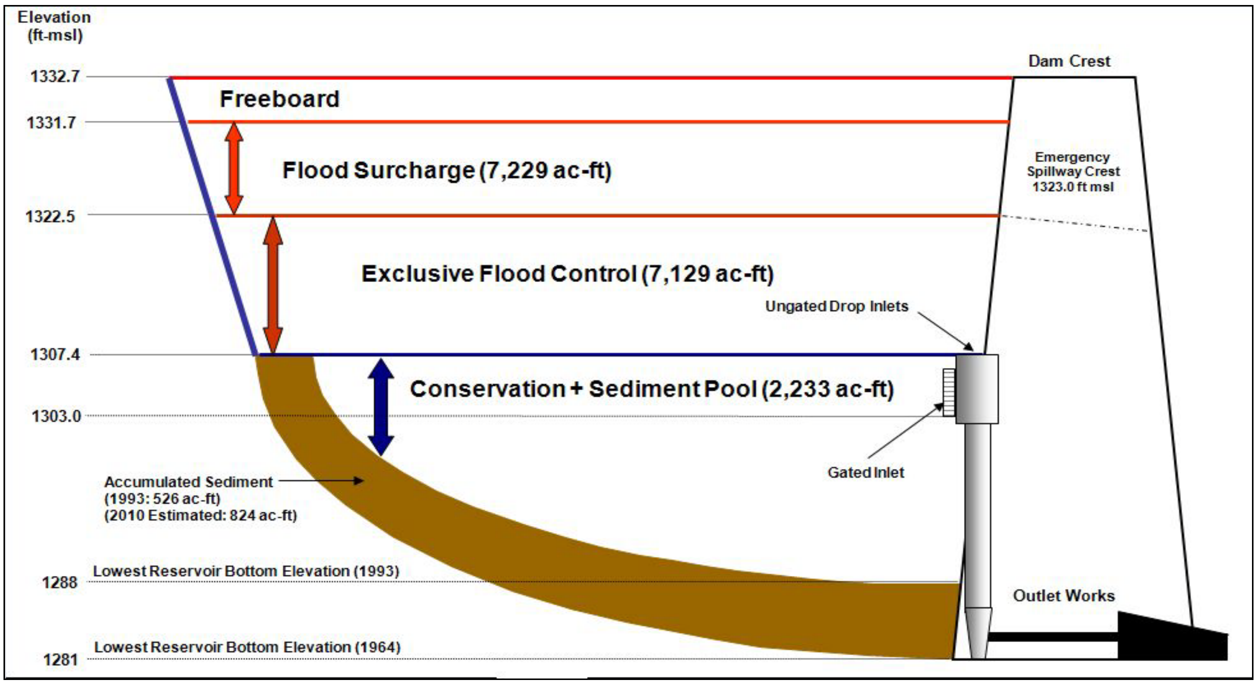

Figure 6.15. Current storage zones of Bluestem Reservoir based on the 1993 survey data and estimated sedimentation.

6.2.2.1.4 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Bluestem Reservoir since the late 1970's. Water quality monitoring locations have included sites in the reservoir and on the inflow and outflow of the reservoir. Figure 6.16 shows the location of the sites that have been monitored for water quality during the past 5 years (i.e., 2006 through 2010). The inflow runoff sites (BLUNFNRT1 and BLUNFWST1) and the in-reservoir bacteria site (BLULKBACT1) were sampled by the Nebraska Department of Environmental Quality (NDEQ). The other in-reservoir sites (BLULKND1, BLULKML1, and BLULKUP1) were sampled by the District. The near-dam location (BLULKND1) has been continuously monitored since 1980.

6.2.2.2 <u>Water Quality in Bluestem Reservoir</u>

6.2.2.2.1 Existing Water Quality Conditions

6.2.2.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Bluestem Reservoir at sites BLULKND1 and BLULKML1 from May through September during the 5-year period 2006 through 2010 are summarized, respectively, in Plates 76 and 77. A review of these results indicated possible water quality concerns regarding dissolved oxygen, nutrients, and selenium.

A few dissolved oxygen measurements throughout Bluestem Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plates 76 and 77). All of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and may have been associated with a slight thermal stratification. Nebraska's Water Quality Standards makes the following provision regarding the application of the State's water quality standards' criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen situation in Bluestem Reservoir, and the measured dissolved oxygen levels below 5 mg/l are not considered to be a water quality standards non-attainment situation.

The chronic selenium criterion for the protection of aquatic life was exceeded in one of five samples collected at the near-dam site (i.e., BLULKND1). At this time the exceedence is considered to be a possible outlier.

Nutrient criteria defined in Nebraska's water quality standards for R13 impounded waters include: total phosphorus (50 ug/l), total nitrogen (1,000 ug/l), and chlorophyll *a* (10 ug/l). All three of these criteria were exceeded throughout Bluestem Reservoir (Plates 76 and 77). The total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 100, 92, and 55 percent of the samples collected at site BLULKND1 (Plate 76). All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" (i.e., May through September) and the reported mean values represent the growing season average for the 5-year period 2006 through 2010. Based on the State of Nebraska's impairment assessment criteria, the total phosphorus mean value of 0.29 mg/l and the total nitrogen mean value of 1.9 mg/l for samples collected at site BLULKND1 indicate impairment of the Aquatic Life beneficial use of Bluestem Reservoir due to nutrients.

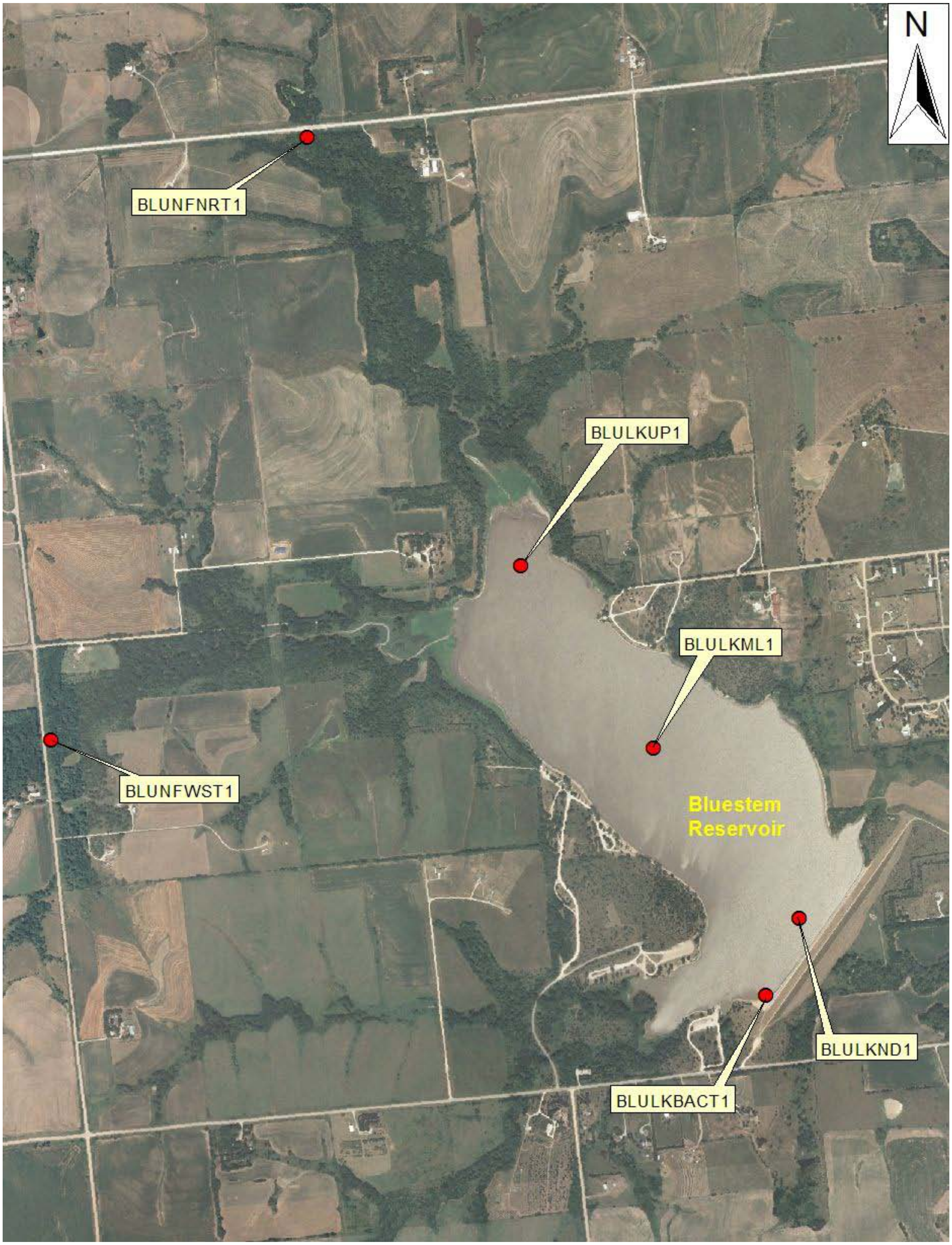

Figure 6.16. Location of sites where water quality monitoring was conducted at Bluestem Reservoir during the period 2006 through 2010.

6.2.2.2.1.2 Thermal Stratification

6.2.2.2.1.2.1 Longitudinal Temperature Contour Plots

Late-spring and summer thermal conditions of Bluestem Reservoir measured during 2009 and 2010 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plates 78 and 79, respectively, provide longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites BLULKND1, BLULKML1, and BLULKUP1 in 2009 and 2010. These temperature plots indicate that appreciable thermal variation was rarely present in Bluestem Reservoir during late-spring and summer. Significant thermal stratification was monitored on one occasion (June 2009) when a 4°C difference was monitored between the surface and bottom water temperatures (Plate 78).

6.2.2.2.1.2.2 Near-Dam Temperature Depth-Profile Plots

Existing summer thermal stratification of Bluestem Reservoir is depicted by the depth-profile temperature plots measured in the deep water area near the dam over the 5-year period 2006 through 2010 (Plate 80). The plotted depth-profile temperature measurements indicate that the reservoir rarely exhibited significant summer thermal stratification over the past 5 years. Since Bluestem Reservoir ices over in the winter and seemingly exhibits frequent or continuous circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.2.2.2.1.3 Summer Dissolved Oxygen Conditions

6.2.2.2.1.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Bluestem Reservoir based on depth-profile measurements taken during 2009 and 2010 at sites BLULKND1, BLULKML1, and BLULKUP1. Plates 81 and 82, respectively, provide longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September in 2009 and 2010. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored on two occasions (June 2009, September 2009) near the reservoir bottom near the dam (Plate 81).

6.2.2.2.1.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

The depth-profile dissolved oxygen measurements collected during the summer over the past 5 years at the deep water area near the dam were compiled and plotted to describe the existing summer dissolved oxygen conditions of Bluestem Reservoir (Plate 83). A few of the plotted profiles indicate an appreciable vertical gradient in dissolved oxygen levels. Most profiles show a fairly constant dissolved oxygen concentration from the reservoir surface to the bottom.

6.2.2.2.1.3.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of Bluestem Reservoir with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2009 and 2010 and the District's current Area-Capacity Tables for the reservoir. The constructed contour plots were reviewed to identify the "worst-case" dissolved oxygen condition. The "worst-case" condition was taken to be the contour plot with the highest elevations of the 5 mg/l and 2.5 mg/l dissolved oxygen isopleths. The June 18, 2009 contour plot indicates a pool elevation of 1306.3 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1297.0 ft-msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1295.0 ft-msl (Plate 81). The current District Area-Capacity Tables (1993 Survey) give storage capacities of 2,204 ac-ft for

elevation 1306.3 ft-msl, 370 ac-ft for elevation 1297.0 ft-msl, and 198 ac-ft for elevation 1295.0 ft-msl. On June 18, 2009 it is estimated that 17 percent of the volume of Bluestem Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 9 percent of the reservoir volume was hypoxic.

6.2.2.2.1.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in Bluestem Reservoir indicated hypoxic conditions were not prevalent during the summers of 2009 and 2010, additional water quality assessment of hypoxic conditions was not conducted.

6.2.2.2.1.5 Water Clarity

6.2.2.2.1.5.1 <u>Secchi Transparency</u>

Figure 6.17 displays a box plot of the Secchi depth transparencies measured at the three in-reservoir monitoring sites (i.e., BLULKND1, BLULKML1, and BLULKUP1) during 2010 (note: the three monitoring sites are oriented in an upstream to downstream direction). The Secchi depth transparencies measured at all three sites were not significantly different (i.e., overlapping inter-quartile ranges). The Secchi depth transparencies measured at Bluestem Reservoir were the lowest measured at any of the Salt Creek Tributary Projects.

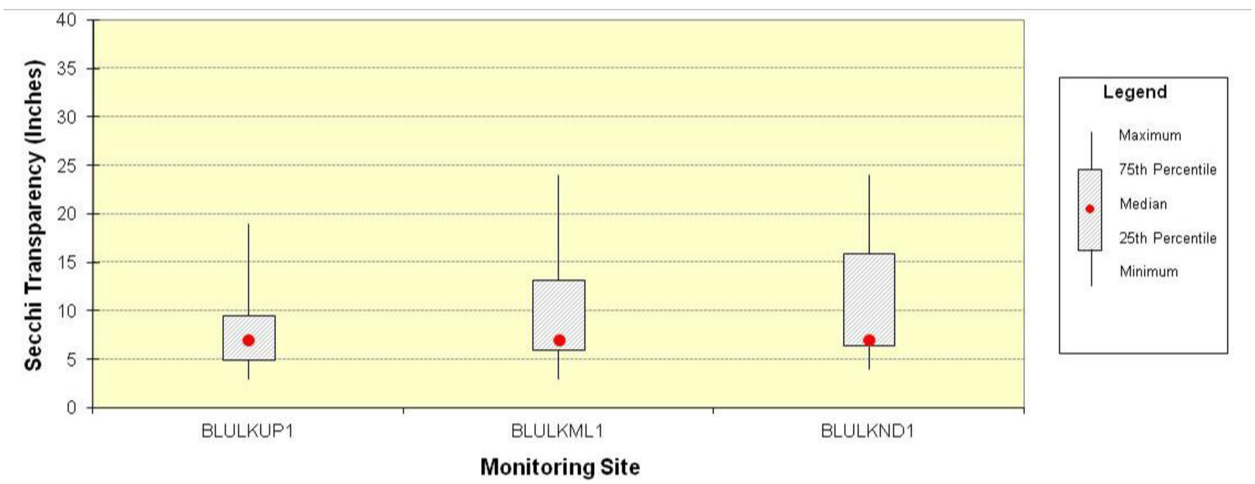

Figure 6.17. Box plot of Secchi depth transparencies measured in Bluestem Reservoir during 2010. (Note: monitoring sites are oriented on the x-axis in an upstream to downstream direction.)**.**

6.2.2.2.1.5.2 <u>Turbidity</u>

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level. Turbidity in water is caused by suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms. Turbidity contour plots were constructed along the length of Bluestem Reservoir based on depth-profile measurements taken during 2009 and 2010. Plates 84 and 85, respectively, provide longitudinal turbidity contour plots based on depth-profile measurements taken from May through September. Bluestem Reservoir occasionally exhibited longitudinal and depth variability in turbidity. Relative to the other Salt Creek tributary reservoirs, Bluestem Reservoir appears to be the most turbid and remains turbid for extended periods following runoff events.

6.2.2.2.1.6 Reservoir Trophic Status

Trophic State Index (TSI) values for Bluestem Reservoir were calculated from monitoring data collected during the 5-year period 2006 through 2010 at the near-dam ambient monitoring site (i.e., BLULKND1). Table 6.8 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Bluestem Reservoir is in a hypereutrophic condition. It is noted that the TSI values are seemingly skewed due to the high turbidity of the reservoir.

Table 6.8. Summary of Trophic State Index (TSI) values calculated for Bluestem Reservoir for the 5-year period 2006 through 2010.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	25	84	85	67	103
TSI(TP)	25	73	72	63	84
TSI(Chl)	25	62	61	40	84
TSI(Avg)	25	73	73	60	82

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values irregardless of the parameters available to calculate the average. Note: See Section 4.1.3 for discussion of TSI calculation.

6.2.2.2.1.7 Monitoring at Swimming Beaches

A designated swimming beach is located on Bluestem Reservoir. Bacteria (i.e., *E. coli*) and the cyanobacteria toxin microcystin were monitored at the swimming beach on the reservoir at site BLULKBACT1 by the NDEQ (Figure 6.16). Bacteria were monitored from May through September over the 5-year period 2006 through 2010, and microcystin was monitored from May through September during the 5-year period 2006 through 2010.

6.2.2.2.1.7.1 <u>Bacteria Monitoring</u>

Table 6.9 summarizes the results of the *E. coli* bacteria monitoring. The “running 5-week” geometric means were calculated as running geometric means for five consecutive weekly bacteria samples through the recreational season (i.e., May through September). The “pooled” geomean was determined by pooling all the weekly bacteria samples collected during the recreational season over the 5-year period and calculating a single geomean. All nondetects were set to 1 to calculate geomeans. The sampling results were compared to the following Nebraska water quality criteria for *E. coli* bacteria:

> *E. coli* bacteria should not exceed a geometric mean of 126/100ml. For increased confidence of the criteria, the geometric mean should be based on a minimum of five samples taken within a 30-day period. Single sample maximum allowable density for designated bathing beaches is 235/100ml.

The 5-year pooled geomean was compared to the State of Nebraska’s impairment assessment criteria regarding the assessment of the Primary Contact Recreation beneficial use using *E. coli* bacteria data. Based on that methodology a Primary Contact Recreation use in Bluestem Reservoir is not impaired due to bacteria. The higher bacteria levels monitored in the reservoir are believed to be associated with runoff events.

Table 6.9. Summary of weekly (May through September) *E. coli* bacteria samples collected at Bluestem Reservoir (i.e., site BLULKBACT1) during the 5-year period 2006 through 2010.

***E. coli* – Individual Samples**		***E. coli* – Geomeans (Running 5-Week)**	
Number of Samples	107	Number of Geomeans	87
Mean (cfu/100ml)	135	Average	70
Median (cfu/100ml)	20	Median	14
Minimum (cfu/100ml)	1	Minimum	1
Maximum (cfu/100ml)	2419	Maximum	483
Percent of samples exceeding 235/100ml	16%	Percent of Geomeans exceeding 126/100ml	18
		***E. coli* – Geomean (5-Year Pooled)**	
		5-Year Pooled Geomean	20

6.2.2.2.1.7.2 Microcystin Monitoring

Cyanobacteria toxins are naturally produced substances stored in the cells of certain species of cyanobacteria (i.e., bluegreen algae). These toxins can be harmful to animals, including humans. Cyanobacteria toxins are known to attack the liver (hepatotoxins) or the nervous system (neurotoxins), others simply irritate the skin. These toxins are usually released into the water when the cyanobacteria cell ruptures or dies. One group of toxins produced and released by cyanobacteria is called microcystin because they were isolated from the cyanobacterium *Microcystis aeruginosa.* Microcystin are the most common of the cyanobacteria toxins found in water, as well as being the ones most often responsible for poisoning animals and humans who come into contact with toxic blooms (Health Canada, 2006). Microcystin toxins are a hepatotoxin and are extremely stable in water because of their chemical structure. They can survive in both warm and cold water and can tolerate radical changes in water chemistry, including pH. Over 50 different kinds of the microcystin toxin have been identified.

Due to human health and other environmental concerns, the NDEQ began monitoring for the cyanobacteria toxin microcystin in 2004. The State of Nebraska issues health advisories and posts swimming beaches if monitored microcystins levels exceed 20 ug/l.

Table 6.10 summarizes the microcystin monitoring conducted at the Bluestem Reservoir swimming beach during the 5-year period 2006 through 2010. These results were compared to the 20 ug/l criterion for issuing health advisories and the posting of swimming beaches. One sample, 1 percent of the collected samples, exceeded the criterion. The monitored levels of microcystin do not indicate a significant cyanobacteria toxin concern at Bluestem Reservoir.

Table 6.10. Summary of weekly (May through September) microcystin samples collected at the Bluestem Reservoir swimming beach (i.e., site BLULKBACT1) during the 5-year period 2006 through 2010.

Summary Statistic	**Swimming Beach (Site BLULKBACT1)**
Number of Samples	108
Minimum (ug/l)	<0.2
25^{th} percentile (ug/l)	<0.2
Median (ug/l)	<0.2
75^{th} Percentile (ug/l)	0.34
Maximum (ug/l)	21.67
Number of samples exceeding 20 ug/l	1
Percent of samples exceeding 20 ug/l	1%

6.2.2.2.2 Water Quality Trends (1980 through 2008)

Water quality trends from 1980 to 2010 were determined for Bluestem Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through October at the near-dam monitoring site (i.e., BLULKND1). Plate 86 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, it appears that Bluestem Reservoir exhibited decreasing transparency, increasing total phosphorus concentrations, and slightly decreasing chlorophyll *a* levels (Plate 86). Over the 31-year period since 1980, Bluestem Reservoir remained in a hypereutrophic condition with a slightly increasing trend in TSI values (Plate 86).

6.2.2.2.3 Existing Water Quality Conditions of Runoff Inflows to Bluestem Reservoir

Existing water quality conditions in the main tributary inflows to Bluestem Reservoir were monitored by the NDEQ during the 5-year period 2004 through 2008. Samples were collected during runoff events from April through September at sites BLUNFNRT1 and BLUNFWST1 (Figure 6.16). Both sites were approximately ½ mile upstream from the reservoir. Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from "base-flow" conditions. Plates 87 and 88, respectively, summarize water quality conditions that were monitored. Tributary inflows to Bluestem Reservoir were not monitored in 2009 and 2010.

6.2.3 BRANCHED OAK RESERVOIR

6.2.3.1 <u>Background Information</u>

6.2.3.1.1 Project Overview

The dam forming Branched Oak Reservoir is located on Oak Creek. The dam was completed on August 21, 1967 and the reservoir reached its initial fill on January 18, 1973. The Branched Oak Reservoir watershed is 89.0 square miles. The watershed was largely agricultural when the dam was built in 1967 and has remained so to the present time.

6.2.3.1.2 Branched Oak Dam Intake Structure

The Branched Oak Dam intake structure is a single reinforced concrete box shaft commonly called a drop inlet structure. Its inside dimensions are 6 feet by 12 feet. The intake structure has two ungated openings, each 42" x 144" with crest elevations at 1284.0 ft-msl. A 48" x 72" gated opening was constructed into the upstream wall of the inlet structure at a crest elevation of 1274.0 ft-msl. The purpose of the gated opening is to lower the level of the conservation pool in order to inspect the conduit, make shoreline repairs, and manage fish populations. A 10" diameter gated opening is located below the weir on the right side wall of the inlet structure at an elevation of 1276.3 ft-msl. This gate may be used to provide water for downstream requirements.

6.2.3.1.3 Reservoir Storage Zones

Figure 6.18 depicts the current storage zones of Branched Oak Reservoir based on the 1991 survey data and estimated sedimentation. It is estimated that 9 percent of the "as-built" volume to the top of the Conservation Pool has been lost to sedimentation as of 2010. The annual volume loss is estimated to be 0.20 percent. Based on the State of Nebraska's impairment assessment methodology, these values indicate that Branched Oak Reservoir's water quality dependent uses are not impaired due to sedimentation.

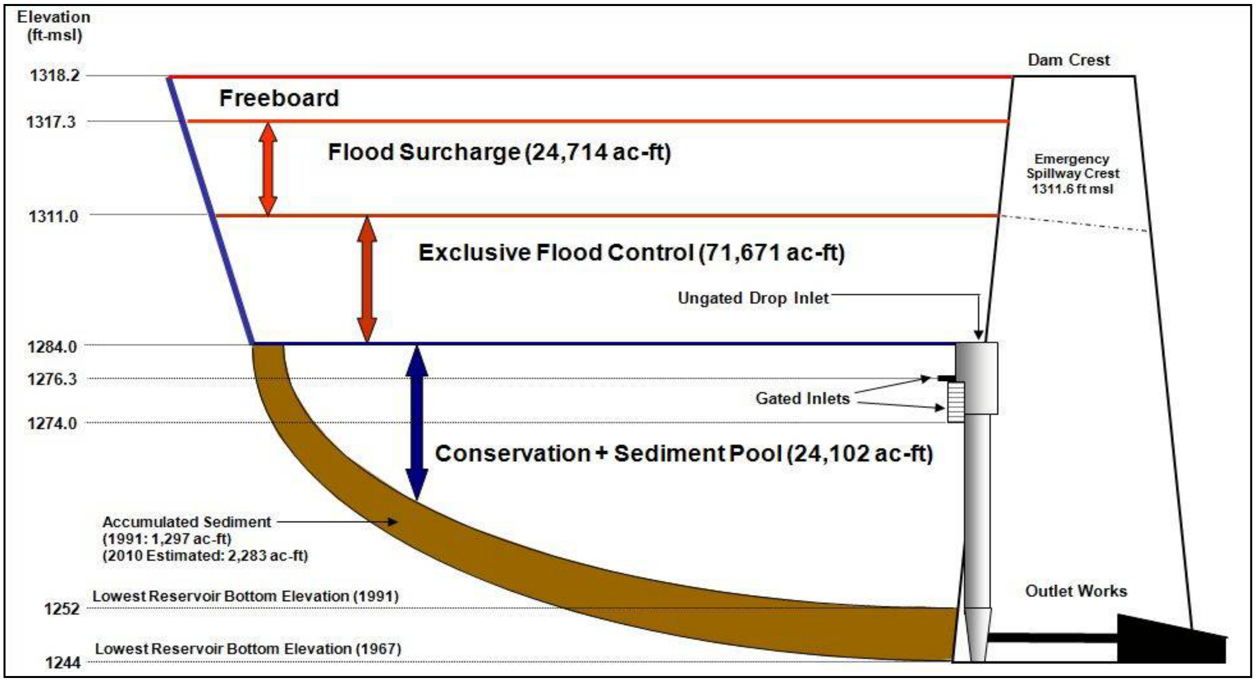

Figure 6.18. Current storage zones of Branched Oak Reservoir based on the 1991 survey data and estimated sedimentation**.**

6.2.3.1.4 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Branched Oak Reservoir since the late 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Figure 6.19 shows the location of the sites that have been monitored for water quality during the past 5 years (i.e., 2006 through 2010). The inflow runoff sites (BOKNFNRT1 and BOKNFWST1) and the in-reservoir bacteria sites (BOKLKBACT1 and BOKLKBACT2) were sampled by the NDEQ. The other in-reservoir sites (BOKLKND1, BOKLKMLN1, BOKLKMLS1, BOKLKUPN1, and BOKLKUPS1) were monitored by the District. The near-dam location (BOKLKND1) has been continuously monitored since 1980.

6.2.3.2 <u>Water Quality in Branched Oak Reservoir</u>

6.2.3.2.1 Existing Water Quality Conditions

6.2.3.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Branched Oak Reservoir at sites BOKLKND1, BOKLKMLN1, and BOKLKMLS1 from May through September during the 5-year period 2006 through 2010 are summarized, respectively, in Plates 89, 90, and 91. A review of these results indicated possible water quality concerns regarding dissolved oxygen, ammonia, and nutrients.

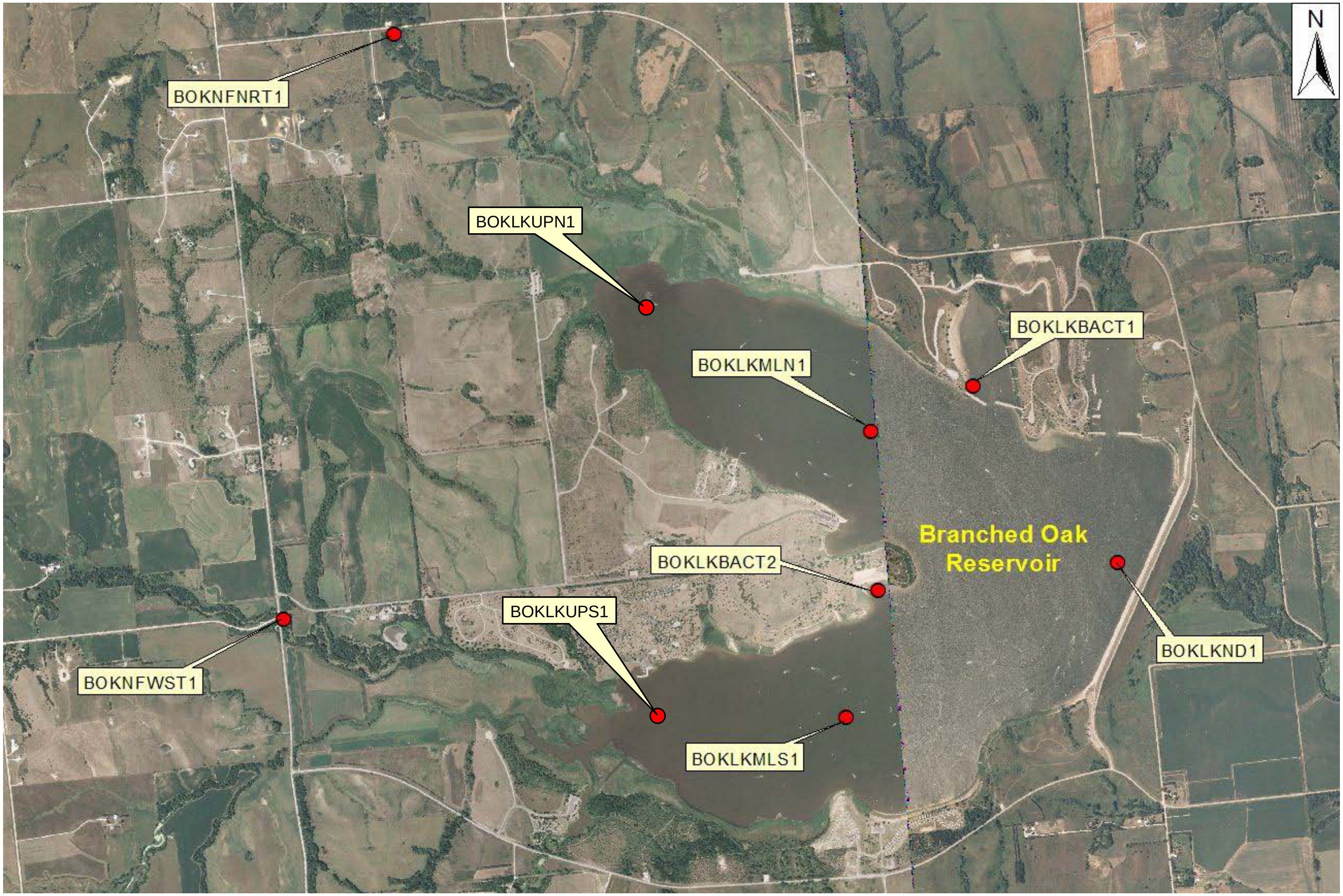

Figure 6.19. Location of sites where water quality monitoring was conducted at Branched Oak Reservoir during the period 2006 through 2010.

A few dissolved oxygen measurements throughout Branched Oak Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plates 89 - 91). All of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and may have been associated with a slight thermal stratification. Nebraska's Water Quality Standards makes the following provision regarding the application of the State's water quality standards' criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen situation in Branched Oak Reservoir, and the measured dissolved oxygen levels below 5 mg/l are not considered to be a water quality standards non-attainment situation.

One sample collected near the dam (i.e., site BOKLKND1) possibly exceeded the chronic ammonia criterion for the protection of warmwater aquatic life (Plate 89). Ammonia criteria are pH and temperature dependant, and the criteria cited are based on median values that may or may not represent conditions when the higher ammonia occurred.

Nutrient criteria defined in Nebraska's water quality standards for R13 impounded waters include: total phosphorus (50 ug/l), total nitrogen (1,000 ug/l), and chlorophyll *a* (10 ug/l). All three of these criteria were exceeded throughout Branched Oak Reservoir (Plate 89 - 91). The total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 82, 68, and 72 percent of the samples collected at site BOKLKND1. All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" (i.e., May through September) and the reported mean values represent the growing season average for the 5-year period 2006 through 2010. Based on the State of Nebraska's impairment assessment methodology, the chlorophyll *a* mean value of 31 ug/l (Plate 89) indicates impairment of the aquatic life beneficial use of Branched Oak Reservoir due to nutrients.

6.2.3.2.1.2 Thermal Stratification

6.2.3.2.1.2.1 <u>Longitudinal Temperature Contour Plots</u>

Late-spring and summer thermal conditions of Branched Oak Reservoir measured during 2009 and 2010 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plates 92 and 93, respectively, provide longitudinal temperature contour plots based on depth-profile temperature measurements. These temperature plots indicate that Branched Oak Reservoir rarely exhibited appreciable thermal variation during late-spring and summer. The maximum difference monitored between the surface and bottom water temperatures during the 2-year period was 7°C (Plates Plates 92 and 93).

6.2.3.2.1.2.2 <u>Near-Dam Temperature Depth-Profile Plots</u>

Existing summer thermal stratification of Branched Oak Reservoir, at the deep water area near the dam, measured over the 5-year period 2006 through 2010 is depicted by depth-profile temperature plots (Plate 94). The depth-profile temperature plots indicate that the reservoir rarely exhibited significant summer thermal stratification over the past 5 years. Since Branched Oak Reservoir ices over in the winter and seemingly exhibits frequent or continuous circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.2.3.2.1.3 Summer Dissolved Oxygen Conditions

6.2.3.2.1.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Branched Oak Reservoir based on depth-profile measurements taken during 2009 and 2010. Plates 95 and 96, respectively, provide longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored along the reservoir bottom near the dam in both years (Plates 95 and 96).

6.2.3.2.1.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

Existing summer dissolved oxygen conditions in Branched Oak Reservoir are described by the dissolved oxygen depth-profiles measured near the dam over the 5-year period 2006 through 2010. Summer depth-profile dissolved oxygen plots were compiled for the 5 years (Plate 97). On several occasions there was a significant vertical gradient in summer dissolved oxygen levels. Although Branched Oak Reservoir appears to be polymictic based on thermal stratification, there appears to be enough inhibition to mixing to allow hypoxic conditions to develop near the reservoir bottom in the area near the dam.

6.2.3.2.1.3.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of Branched Oak Reservoir with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2009 and 2010 and the District's current Area-Capacity Tables (1991 Survey) for the reservoir. The constructed contour plots were reviewed to identify the "worst-case" dissolved oxygen condition. The "worst-case" condition was taken to be the contour plot with the highest elevations of the 5 mg/l and 2.5 mg/l dissolved oxygen isopleths. The July 7, 2009 contour plot indicates a pool elevation of 1284.4 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1271.0 ft msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1269.0 ft-msl (Plate 95). The current District Area-Capacity Tables give storage capacities of 25,840 ac-ft for elevation 1284.4 ft-msl, 7,329 ac-ft for elevation 1271.0 ft-msl, and 5,621 ac-ft for elevation 1269.0 ft-msl. On July 7, 2009 it is estimated that 28 percent of the volume of Branched Oak Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 22 percent of the reservoir volume was hypoxic.

6.2.3.2.1.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in Branched Oak Reservoir indicated hypoxic conditions were common during the summers of 2009 and 2010, longitudinal contour and depth-profile plots were constructed for ORP and pH. Near-surface and near-bottom water quality samples collected when hypoxia was present were also compared.

6.2.3.2.1.4.1 Oxidation-Reduction Potential

Plates 98 and 99, respectively, provide longitudinal ORP contour plots based on depth-profile measurements taken in 2009 and 2010. The ORP values indicated reduced conditions present near the bottom of Branched Oak Reservoir in August 2010 (Plate 99). Plate 100 plots depth profiles for ORP measured during the summer over the past 5 years in the deep water area of Branched Oak Reservoir near the dam. ORP values approaching -100 mV occasionally occur near the bottom of Branched Oak Reservoir during the summer. However, given the polymictic nature of the reservoir these conditions seemingly are not long-term.

6.2.3.2.1.4.2 pH

Longitudinal contour plots for pH conditions measured in 2009 and 2010 are provided, respectively, in Plates 101 and 102. Occasional reduced conditions in the deeper water of Branched Oak Reservoir seemingly lead to in lower pH levels near the reservoir bottom (Plates 101 and 102). The lowest measured pH levels near the reservoir bottom were above the lower pH criterion of 6.5 for the protection of warmwater aquatic life. Plate 103 plots depth profiles for pH measured during the summer over the past 5 years in the deep water area of Branched Oak Reservoir near the dam. An appreciable vertical gradient in pH rarely occurred in the reservoir during the summer (Plate 103).

6.2.3.2.1.4.3 Comparison of Near-Surface and Near-Bottom Water Quality Conditions

Paired near-surface and near-bottom water quality samples collected from Branched Oak Reservoir during the summer when hypoxia was present were compared. Near-surface conditions were represented by samples collected within 1-meter of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site BOKLKND1 during the 5-year period 2006 through 2010. During the 5-year period a total of 25 paired samples were collected monthly from May through September. Of the 25 paired samples collected, nine (36%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature (9), dissolved oxygen (9), oxidation-reduction potential (9), pH (9), alkalinity (7), total ammonia (7), nitrate-nitrate nitrogen (7), total phosphorus (7), and orthophosphorus (7) (Plate 104) *[Note: the number in parentheses is the number of paired observations available for each parameter]*. A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were not significantly different for nitrate-nitrite nitrogen, total alkalinity, total phosphorus, or ortho-phosphorus. Parameters that were significantly lower in the near-bottom water of Branched Oak Reservoir when hypoxia was present included: water temperature ($p < 0.0001$), dissolved oxygen ($p < 0.0001$), ORP ($p < 0.01$), and pH ($p < 0.0001$). Parameters that were significantly higher in the near-bottom water included: total ammonia ($p < 0.01$).

6.2.3.2.1.5 Water Clarity

6.2.3.2.1.5.1 Secchi Transparency

Figure 6.20 displays a box plot of the Secchi depth transparencies measured at the five in-reservoir monitoring sites (i.e., BOKLKND1, BOKLKMLN1, BOKLKMLS1, BOKLKUPN1, and BOKLKUPS1) from 2008 through 2010 (note: the monitoring sites are oriented in an upstream to downstream direction). The Secchi depth transparencies measured in Branched Oak Reservoir increased in a downstream direction, and the water near the dam was significantly clearer than in the upper reaches of the south and north arms of the reservoir (Figure 6.20).

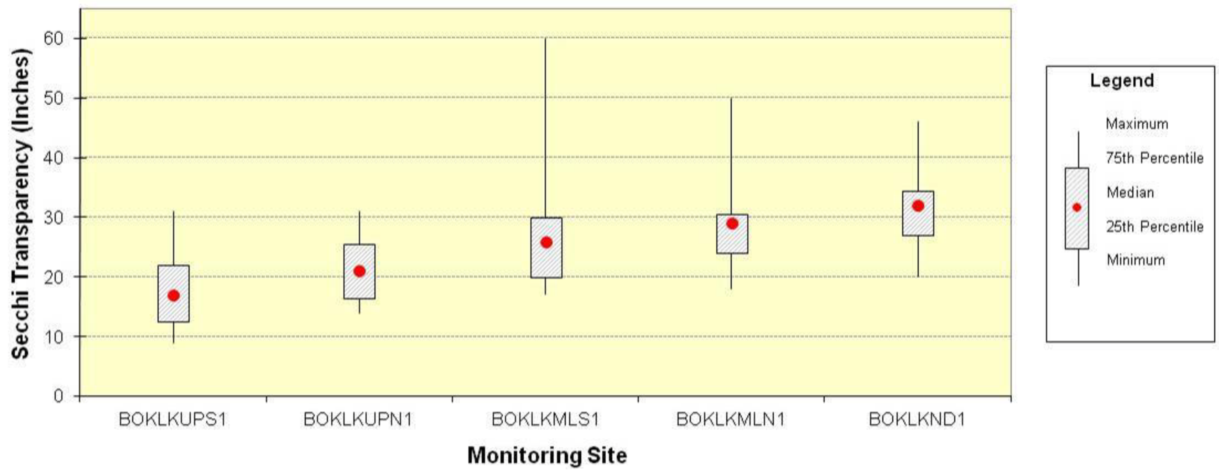

Figure 6.20. Box plot of Secchi depth transparencies measured in Branched Oak Reservoir from 2008 through 2010. (Note: monitoring sites are oriented on the x-axis in an upstream to downstream direction.)**.**

6.2.3.2.1.5.2 Turbidity

Turbidity contour plots were constructed along the length of Branched Oak Reservoir based on depth-profile measurements taken during 2009 and 2010. Plates 105 and 106, respectively, provide longitudinal turbidity contour plots based on depth-profile measurements taken from May through September. Branched Oak Reservoir exhibited some longitudinal, vertical, and temporal variation in turbidity. The variation of turbidity in the reservoir is seemingly associated with runoff events that caused significant increases in turbidity in the upper reaches which then moved along the reservoir bottom.

6.2.3.2.1.6 Reservoir Trophic Status

Trophic State Index (TSI) values for Branched Oak Reservoir were calculated from monitoring data collected during the 5-year period 2006 through 2010 at the near-dam ambient monitoring site (i.e., BOKLKND1). Table 6.11 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Branched Oak Reservoir is in a slightly hypereutrophic condition.

Table 6.11. Summary of Trophic State Index (TSI) values calculated for Branched Oak Reservoir for the 5-year period 2006 through 2010.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	25	64	64	58	71
TSI(TP)	25	61	61	55	69
TSI(Chl)	25	68	75	40	84
TSI(Avg)	25	65	66	51	72

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values irregardless of the parameters available to calculate the average.
Note: See Section 4.1.3 for discussion of TSI calculation.

6.2.3.2.1.7 Monitoring at Swimming Beaches

Two designated swimming beaches are located on Branched Oak Reservoir. Bacteria (i.e., *E. coli*) and the cyanobacterial toxin microcystin were monitored at the two swimming beaches (i.e., sites BOKLKBACT1 and BOKLKBACT2) by the NDEQ during the past 5 years. Bacteria and cyanobacterial toxins were monitored from May through September over the 5-year period 2006 through 2010.

6.2.3.2.1.7.1 Bacteria Monitoring

Table 6.12 summarizes the results of the bacteria sampling. The "running 5-week" geometric means were calculated as running geometric means for five consecutive weekly bacteria samples through the recreational season (i.e., May through September). The "pooled" geomean was determined by pooling all the weekly bacteria samples collected during the recreational season over the 5-year period and calculating a single geomean. All nondetects were set to 1 to calculate geomeans. The sampling results were compared to the following Nebraska water quality criteria for *E. coli* bacteria:

> *E. coli* bacteria should not exceed a geometric mean of 126/100ml. For increased confidence of the criteria, the geometric mean should be based on a minimum of five samples taken within a 30-day period. Single sample maximum allowable density for designated bathing beaches is 235/100ml.

The pooled geomeans were compared to the State of Nebraska's impairment assessment criteria regarding the assessment of the Primary Contact Recreation beneficial use using *E. coli* bacteria data. Based on those criteria a Primary Contact Recreation use in Branched Oak Reservoir is not impaired due to bacteria. The higher bacteria levels monitored in the reservoir are believed to be associated with runoff events.

Table 6.12. Summary of weekly (May through September) bacteria samples collected at Branched Oak Reservoir (i.e., sites BOKLKBACT1 and BOKLKBACT2) during the 5-year period 2006 through 2010.

North Swimming Beach Site: BOKLKBACT1			
***E. coli* Bacteria – Individual Samples**		***E. coli* Bacteria – Geomeans**	
Number of Samples	106	Number of Geomeans	87
Mean (cfu/100ml)	129	Average	34
Median (cfu/100ml)	20	Median	23
Minimum (cfu/100ml)	1	Minimum	5
Maximum (cfu/100ml)	2,419	Maximum	135
Percent of samples exceeding 235/100ml	9%	Percent of Geomeans exceeding 126/100ml	3%
		***E. coli* – Geomean (5-Year Pooled)**	
		5-Year Pooled Geomean	27
South Swimming Beach Site: BOKLKBACT2			
***E. coli* Bacteria – Individual Samples**		***E. coli* Bacteria – Geomeans**	
Number of Samples	106	Number of Geomeans	87
Mean (cfu/100ml)	150	Average	31
Median (cfu/100ml)	17	Median	23
Minimum (cfu/100ml)	1	Minimum	2
Maximum (cfu/100ml)	3,873	Maximum	159
Percent of samples exceeding 235/100ml	10%	Percent of Geomeans exceeding 126/100ml	5%
		***E. coli* – Geomean (5-Year Pooled)**	
		5-Year Pooled Geomean	21

6.2.3.2.1.7.2 Microcystin Monitoring

Table 6.13 summarizes the microcystin monitoring conducted at the Branched Oak Reservoir swimming beaches during the 4-year period 2006 through 2010. These results were compared to the 20 ug/l criterion for issuing health advisories and the posting of swimming beaches. No samples exceeded the criterion. The monitored levels of microcystin do not indicate a significant cyanobacteria toxin concern at Branched Oak Reservoir.

Table 6.13. Summary of weekly (May through September) microcystin samples collected at Branched Oak Reservoir (i.e., sites BOKLKBACT1 and BOKLKBACT2) during the 5-year period 2006 through 2010.

Summary Statistic	**North Swimming Beach (Site BOKLKBACT1)**	**South Swimming Beach (Site BOKLKBACT2)**
Number of Samples	86	86
Minimum (ug/l)	<0.2	<0.2
25th percentile (ug/l)	<0.2	<0.2
Median (ug/l)	0.6	0.5
75th Percentile (ug/l)	1.3	1.2
Maximum (ug/l)	6.9	10.4
Percent of samples exceeding 20 ug/l	0%	0%

6.2.3.2.2 Water Quality Trends (1980 through 2010)

Water quality trends from 1980 to 2010 were determined for Branched Oak Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through October at the near-dam monitoring site (i.e., BOKLKND1). Plate 107 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, it appears that Branched Oak Reservoir exhibited decreasing transparency and increasing total phosphorus and chlorophyll *a* levels (Plate 107). Over the 31-year period since 1980, Branched Oak Reservoir moved from a eutrophic to hypereutrophic condition (Plate 107).

6.2.3.2.3 Existing Water Quality Conditions of Runoff Inflows to Branched Oak Reservoir

Existing water quality conditions in the main tributary inflows to Branched Oak Reservoir were monitored by the NDEQ under runoff conditions, during the period of April through September, at two sites BOKNFNRT1 and BOKNFWST1 (Figure 6.19). Both sites were approximately ½ mile upstream from the reservoir. Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from “base-flow” conditions. Plates 108 and 109, respectively, summarize water quality conditions that were monitored at sites BOKNFNRT1 and BOKNFWST1 under runoff conditions during the period 2004 through 2008. Tributary inflows to Branched Oak Reservoir were not monitored in 2009 and 2010.

6.2.4 CONESTOGA RESERVOIR

6.2.4.1 <u>Background Information</u>

6.2.4.1.1 Project Overview

The dam forming Conestoga Reservoir is located on Holmes Creek. The dam was completed on September 24, 1963 and the reservoir reached its initial fill in May 1965. The Conestoga Reservoir watershed is 15.1 square miles. The watershed was largely agricultural when the dam was built in 1963 and has remained so to the present time.

6.2.4.1.2 Conestoga Dam Intake Structure

The dam intake at Conestoga Dam is a drop inlet structure consisting of a single reinforced concrete box shaft. Its inside dimensions are 5 feet by 8 feet. The intake structure has four ungated openings – two 30” x 96” openings with a crest elevation at 1242.3 ft-msl and two 12” x 54” openings with a crest elevation at 1232.9. A 36” x 36” gated opening with a crest elevation of 1228.0 ft-msl was constructed into the upstream wall. The purpose of the gated opening is to lower the level of the conservation pool in order to inspect the conduit, make shoreline repairs, and manage fish populations. It may also be used to release water for downstream needs.

6.2.4.1.3 Reservoir Storage Zones

Figure 6.21 depicts the current storage zones of Conestoga Reservoir based on the 1996 survey data and estimated sedimentation. It is estimated that 31 to 38 percent of the “as-built” volume to the top of the Conservation Pool has been lost to sedimentation as of 2010. The annual volume loss is estimated to be 0.65 to 0.81 percent. Based on the State of Nebraska’s impairment assessment criteria, these values indicate that Conestoga Reservoir’s water quality dependent uses are impaired due to sedimentation.

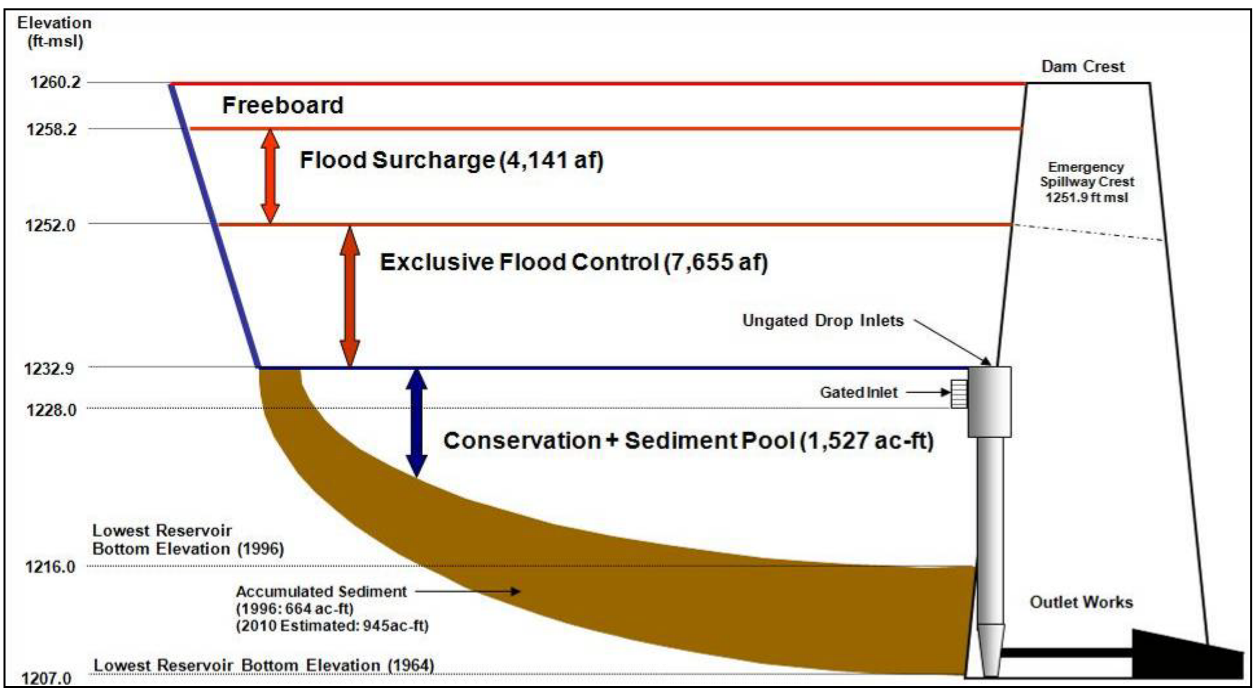

Figure 6.21. Current storage zones of Conestoga Reservoir based on the 1996 survey data and estimated sedimentation**.**

6.2.4.1.4 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Conestoga Reservoir since the late 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Figure 6.22 shows the location of the sites that have been monitored for water quality during the past 5 years (i.e., 2006 through 2010). The inflow runoff sites (CONNFNRT1 and CONNFWST1) and the in-reservoir bacteria site (CONLKBACT1) were sampled by the NDEQ from 2004. The other in-reservoir sites (CONLKND1, CONLKML1, and CONLKUP1) were sampled by the District. The near-dam location (CONLKND1) has been continuously monitored by the District since 1980.

6.2.4.2 <u>Water Quality in Conestoga Reservoir</u>

6.2.4.2.1 Existing Water Quality Conditions

6.2.4.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Conestoga Reservoir at sites CONLKND1 and CONLKML1 from May through September during the 5-year period 2006 through 2010 are summarized, respectively, in Plates 110 and 111. A review of these results indicated possible water quality concerns regarding dissolved oxygen, pH, selenium, and nutrients.

A small number (<15%) of dissolved oxygen measurements throughout Conestoga Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plates 110 and 111). All of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and may have been associated with a slight thermal stratification. Nebraska's Water Quality Standards makes the following provision regarding the application of the State's water quality standards' criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen situation in Conestoga Reservoir, and the lower dissolved oxygen levels are not considered to be a water quality standards non-attainment situation.

A small number (≤1%) of pH readings throughout Conestoga Reservoir were above the numeric pH criteria of 9.0 for the protection of warmwater aquatic life (Plates 110 and 111). The magnitude and small number of pH criterion exceedences are not believed to be a significant concern at this time. It is believed the high pH values may be associated with periods of high algal production and CO_2 uptake during photosynthesis.

One selenium measurement (20%) exceeded the chronic criterion for the protection of aquatic life. At this time the exceedence is considered to be a possible outlier.

Nutrient criteria defined in Nebraska's water quality standards for R13 impounded waters include: total phosphorus (50 ug/l), total nitrogen (1,000 ug/l), and chlorophyll *a* (10 ug/l). All three of these criteria were exceeded throughout Conestoga Reservoir (Plate 110 and 111). The total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 98, 96, and 75 percent of the samples collected at site CONLKND1. All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" (i.e., May through September) and the reported mean values represent the growing season average for the 5-year period 2006 through 2010. Based on the State of Nebraska's impairment assessment criteria, the mean values for the three parameters (Plate 110) indicate impairment of the aquatic life beneficial use of Conestoga Reservoir due to nutrients.

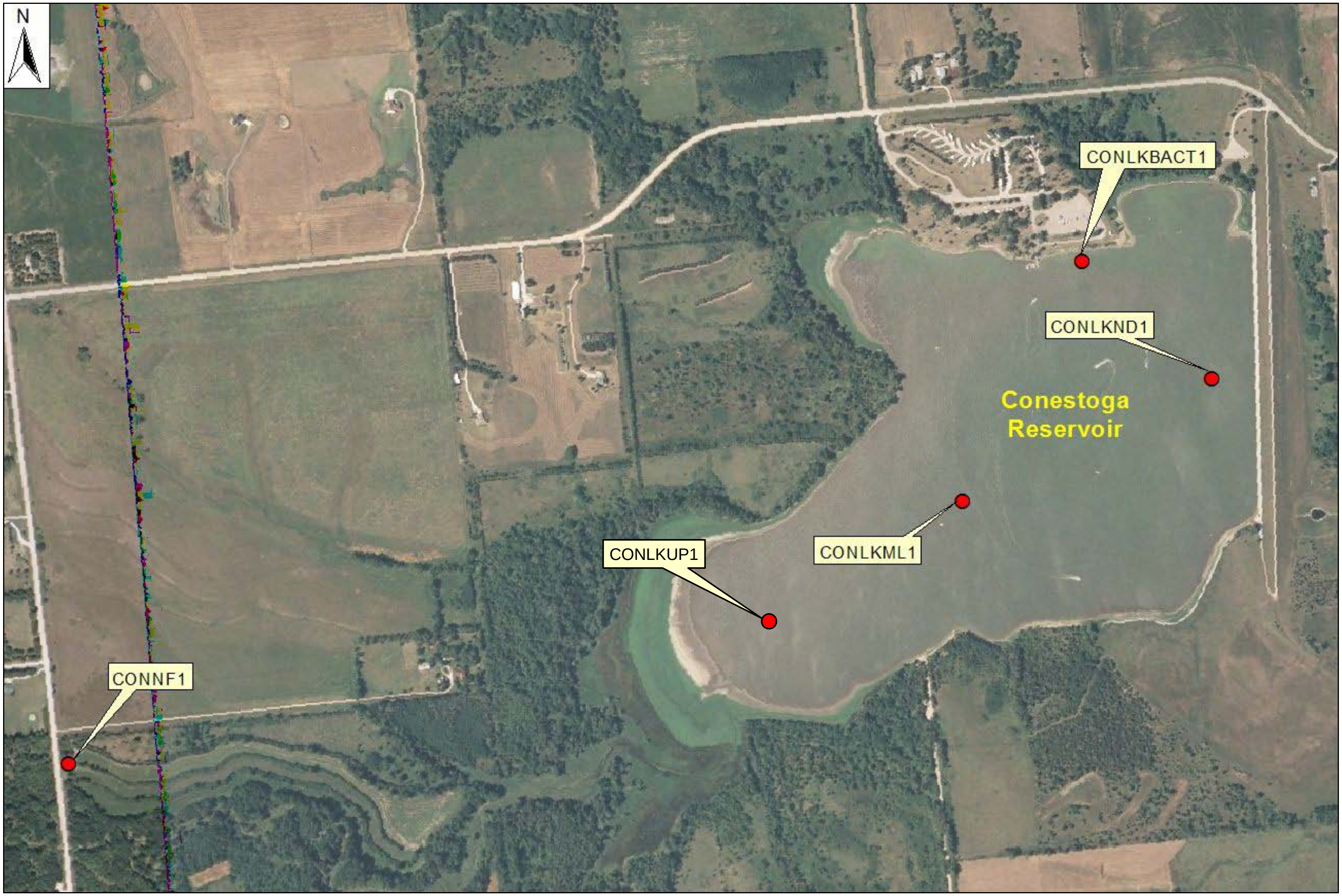

Figure 6.22. Location of sites where water quality monitoring was conducted at Conestoga Reservoir during the period 2006 through 2010.

6.2.4.2.1.2 Thermal Stratification

6.2.4.2.1.2.1 Longitudinal Temperature Contour Plots

Late-spring and summer thermal conditions of Conestoga Reservoir measured during 2009 and 2010 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plates 112 and 113, respectively, provide longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites CONLKND1, CONLKML1, and CONLKUP1 in 2009 and 2010. These temperature plots indicate that Conestoga Reservoir occasionally exhibited appreciable thermal variation during late-spring and summer. The maximum difference monitored between the surface and bottom water temperatures during the 2-year period was 4°C in July and August of 2010 (Plate 113).

6.2.4.2.1.2.2 Near-Dam Temperature Depth-Profile Plots

Existing summer thermal stratification of Conestoga Reservoir, at the deep water area near the dam, is described by the depth-profile temperature plots measured over the past 5 years. Depth-profile temperature plots measured during the summer were compiled (Plate 114). The plotted depth-profile temperature measurements indicate that the reservoir rarely exhibits significant summer thermal stratification. Since Conestoga Reservoir ices over in the winter and seemingly exhibits frequent or continuous circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.2.4.2.1.3 Summer Dissolved Oxygen Conditions

6.2.4.2.1.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Conestoga Reservoir based on depth-profile measurements taken during 2009 and 2010 at sites CONLKND1, CONLKML1, and CONLKUP1. Plates 115 and 116, respectively, provide longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September in 2009 and 2010. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored on three occasions (July 2009, July and August 2010) near the reservoir bottom near the dam (Plate 116).

6.2.4.2.1.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

The depth-profile dissolved oxygen measurements collected during the summer over the past 5 years at the deep water area near the dam were plotted and compiled to describe the existing summer dissolved oxygen conditions of Conestoga Reservoir (Plate 117). A few of the plotted profiles indicate an appreciable vertical gradient in dissolved oxygen levels. Most of the profiles show a fairly constant dissolved oxygen concentration above 5 mg/l from the reservoir surface to the bottom. This is attributed to the polymictic nature of the reservoir.

6.2.4.2.1.3.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of Conestoga Reservoir with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2009 and 2010 and the District's current Area-Capacity Tables (1996 Survey) for the reservoir. The constructed contour plots were reviewed to identify the "worst-case" dissolved oxygen condition. The "worst-case" condition was taken to be the contour plot with the highest elevations of the 5 mg/l and 2.5 mg/l dissolved oxygen isopleths. The August 11, 2010 contour plot indicates a pool elevation of 1233.0 ft-msl, a 5 mg/l dissolved oxygen

isopleth elevation of about 1225.0 ft msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1224.0 ft-msl (Plate 116). The current District Area-Capacity Tables give storage capacities of 1,829 ac-ft for elevation 1233.0 ft-msl, 540 ac-ft for elevation 1225.0 ft-msl, and 442 ac-ft for elevation 1224.0 ft-msl. On August 11, 2010 it is estimated that 30 percent of the volume of Conestoga Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 24 percent of the reservoir volume was hypoxic.

6.2.4.2.1.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in Conestoga Reservoir indicated hypoxic conditions were not prevalent during the summers of 2009 and 2010, additional water quality assessment of hypoxic conditions was not conducted.

6.2.4.2.1.5 Water Clarity

6.2.4.2.1.5.1 Secchi Transparency

Figure 6.23 displays a box plot of the Secchi depth transparencies measured at the three in-reservoir monitoring sites (i.e., CONLKND1, CONLKML1, and CONLKUP1) during 2010 (note: the monitoring sites are oriented in an upstream to downstream direction). Secchi depth transparencies measured in Conestoga Reservoir increased in a downstream direction, but water at the mid-lake and near-dam sites was not significantly clearer than in the upper reaches of the reservoir (Figure 6.23).

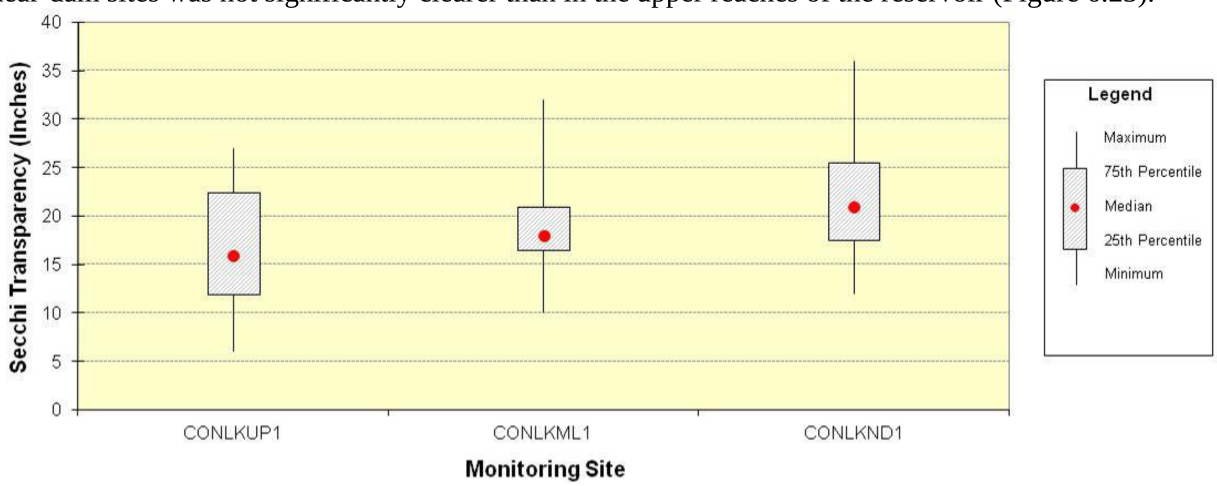

Figure 6.23. Box plot of Secchi depth transparencies measured in Conestoga Reservoir during 2010. (Note: monitoring sites are oriented on the x-axis in an upstream to downstream direction.)**.**

6.2.4.2.1.5.2 Turbidity

Turbidity contour plots were constructed along the length of Conestoga Reservoir based on depth-profile measurements taken during 2009 and 2010. Plates 118 and 119, respectively, provide longitudinal turbidity contour plots based on depth-profile measurements taken from May through September. Conestoga Reservoir commonly exhibited longitudinal and depth variability in turbidity (Plate 118 and 119).

6.2.4.2.1.6 Reservoir Trophic Status

Trophic State Index (TSI) values for Conestoga Reservoir were calculated from monitoring data collected during the 5-year period 2006 through 2010 at the near-dam ambient monitoring site (i.e., CONLKND1). Table 6.14 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Conestoga Reservoir is in a hypereutrophic condition.

Table 6.14. Summary of Trophic State Index (TSI) values calculated for Conestoga Reservoir for the 5-year period 2006 through 2010.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	25	71	71	61	81
TSI(TP)	25	67	66	59	80
TSI(Chl)	24	70	74	40	88
TSI(Avg)	25	69	69	60	76

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values irregardless of the parameters available to calculate the average.
Note: See Section 4.1.3 for discussion of TSI calculation.

6.2.4.2.1.7 Monitoring at Swimming Beaches

A designated swimming beach is located on Conestoga Reservoir. Bacteria (i.e., *E. coli*) and the cyanobacteria toxin microcystin were monitored at the swimming beach on the reservoir at site CONLKBACT1 by the NDEQ (Figure 6.16). Bacteria and microcystin were monitored from May through September over the 5-year period 2006 through 2010.

6.2.4.2.1.7.1 <u>Bacteria Monitoring</u>

Table 6.15 summarizes the results of the *E. coli* bacteria monitoring. The "running 5-week" geometric means were calculated as running geometric means for five consecutive weekly bacteria samples through the recreational season (i.e., May through September). The "pooled" geomean was determined by pooling all the weekly bacteria samples collected during the recreational season over the 5-year period and calculating a single geomean. All nondetects were set to 1 to calculate geomeans. The sampling results were compared to the following Nebraska water quality criteria for *E. coli* bacteria:

> *E. coli* bacteria should not exceed a geometric mean of 126/100ml. For increased confidence of the criteria, the geometric mean should be based on a minimum of five samples taken within a 30-day period. Single sample maximum allowable density for designated bathing beaches is 235/100ml.

The pooled geomean was compared to the State of Nebraska's impairment assessment criteria regarding the assessment of the Primary Contact Recreation beneficial use using *E. coli* bacteria data. Based on these criteria a Primary Contact Recreation use in Conestoga Reservoir is not impaired due to bacteria. The higher bacteria levels monitored in the reservoir are believed to be associated with runoff events.

Table 6.15. Summary of weekly (May through September) *E. coli* bacteria samples collected at Conestoga Reservoir (i.e., site CONLKBACT1) during the 5-year period 2006 through 2010.

E. coli **– Individual Samples**		***E. coli*** **– Geomeans (Running 5-Week)**	
Number of Samples	107	Number of Geomeans	87
Mean (cfu/100ml)	32	Average	15
Median (cfu/100ml)	6	Median	6
Minimum (cfu/100ml)	1	Minimum	1
Maximum (cfu/100ml)	613	Maximum	160
Percent of samples exceeding 235/100ml	4%	Number of Geomeans exceeding 126/100ml	1
		E. coli **– Geomean (5-Year Pooled)**	
		5-Year Pooled Geomean	7

6.2.4.2.1.7.2 Microcystin Monitoring

Table 6.16 summarizes the microcystin monitoring conducted at the Conestoga Reservoir swimming beach during the 5-year period 2006 through 2010. These results were compared to the 20 ug/l criterion for issuing health advisories and the posting of swimming beaches. Three samples (3%) exceeded the criterion. Based on the State of Nebraska's impairment assessment criteria (Tables 4.2 and 4.5), the monitored levels of microcystin do not indicate a significant cyanobacteria toxin concern at Conestoga Reservoir.

Table 6.16. Summary of weekly (May through September) microcystin samples collected at the Conestoga Reservoir swimming beach (i.e., site CONLKBACT1) during the 4-year period 2006 through 2010.

Summary Statistic	Swimming Beach (Site CONLKBACT1)
Number of Samples	108
Minimum (ug/l)	n.d.
25^{th} percentile (ug/l)	0.09
Median (ug/l)	.32
75^{th} Percentile (ug/l)	1.9
Maximum (ug/l)	40
Number of samples exceeding 20 ug/l	3
Percent of samples exceeding 20 ug/l	3%

6.2.4.2.2 Water Quality Trends (1980 through 2008)

Water quality trends from 1980 to 2010 were determined for Conestoga Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through September at the near-dam monitoring site (i.e., CONLKND1). Plate 120 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, it appears that Conestoga Reservoir exhibited no noticeable change in transparency and increases in total phosphorus concentrations and chlorophyll *a* levels (Plate 120). Over the 31-year period since 1980, Conestoga Reservoir moved from a eutrophic to hypereutrophic condition (Plate 120).

6.2.4.2.3 Existing Water Quality Conditions of Runoff Inflows to Conestoga Reservoir

Existing water quality conditions in the main tributary inflow to Conestoga Reservoir was monitored at site CONNF1 by the NDEQ under runoff conditions during the period of April through September (Figure 6.22). Site CONNF1 was approximately ½ mile upstream from the reservoir. Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from "base-flow" conditions. Plate 121 summarizes water quality conditions that were monitored at site CONNF1 under runoff conditions during the period 2004 through 2008. Tributary inflows to Conestoga Reservoir were not monitored in 2009 and 2010.

6.2.5 HOLMES RESERVOIR

6.2.5.1 Background Information

6.2.5.1.1 Project Overview

The dam forming Holmes Reservoir is located on Antelope Creek in the City of Lincoln. The dam was completed on September 17, 1962 and the reservoir reached its initial fill on June 2, 1965. The Holmes Reservoir watershed is 5.4 square miles. The watershed was largely agricultural when the dam was built in 1962; however since then, the watershed has undergone extensive urbanization with the growth of Lincoln.

6.2.5.1.2 Aquatic Habitat Improvement and Water Quality Management Project

Over $5.5 million in State and Federal funds were used to by the State of Nebraska to implement a lake restoration project at Holmes Reservoir. The project, completed in 2005, implemented numerous measures to improve the aquatic habitat, water quality, and the fishery of the reservoir. Implemented measures included off-line wetlands east of 70th Street, headwater wetlands north of Pioneers Boulevard, outlet modifications, construction of four jetties, two offshore breakwaters, a wooden fishing pier, three bridges, offset sediment dikes on each reservoir arm, and excavation of the reservoir basin. Approximately 320,750 cubic yards (CY) of sediment was excavated from the reservoir basin; 240,000 CY was completely removed, 61,000 CY was used in jetties and breakwaters, and 20,000 CY was incorporated into wetland construction. The excavation restored an estimated 52 percent of the original conservation pool volume and increased deep water (i.e. over 10 feet) by 111 percent. Existing and newly constructed wetlands are expected to reduce sediment loading from 21,877 tons to below 5,000 tons annually. Shoreline features such as jetties and breakwaters have added over 5,000 feet of new, productive shoreline while protecting against erosion. This represents a 21 percent increase in shoreline length. Collectively, basin excavation, shoreline stabilization features, sediment retention structures, and wetlands are expected to add 87 years to the recreational life of the reservoir. The fish community was also renovated and restocked. To increase recreational fishing opportunities, rainbow trout are annually scheduled for stocking into the south arm of the reservoir each fall and spring.

6.2.5.1.3 Holmes Dam Intake Structure

The dam intake at Holmes Dam is a drop inlet structure consisting of a single reinforced concrete box shaft. Its inside dimensions are 5 feet by 8 feet. The intake structure has four ungated openings – two 30” x 96” openings with a crest elevation at 1249.0 ft-msl and two 12” x 36” openings with a crest elevation at 1242.5 ft-msl. A 36” x 36” gated opening with a crest elevation of 1239.0 ft-msl was constructed into the upstream wall. As part of the recent lake renovation project a new low-level gated opening was installed in the drop inlet structure. The new low-level gated opening is 45” x 45” with a crest elevation of 1230.6 ft-msl. The purpose of the new low-level gated opening is to allow for better management of pool elevations for water quality and fishery management. It may also be used to release water for downstream needs.

6.2.5.1.4 Reservoir Storage Zones

Figure 6.24 depicts the current storage zones of Holmes Reservoir based on recent NGPC survey data, results of the recent lake renovation project, and estimated sedimentation. After accounting for the sediment removed from the reservoir basin as part of the recent lake renovation project, it is estimated that 16 percent of the “as-built” volume to the top of the Conservation Pool has been lost to sedimentation as of 2010. The annual volume loss, prior to the implementation of the lake renovation project, is estimated to be 0.84 percent. However, measures implemented as part of, or in conjunction with, the lake

renovation project (e.g., off-line wetlands, headwater wetlands, Antelope Commons wetlands, riparian vegetative plantings, stormwater management, etc.) are believed to have significantly reduced the annual volume loss below 0.84 percent. Based on the State of Nebraska's impairment assessment criteria, these values indicate that Holmes Reservoir's water quality dependent uses are not impaired due to sedimentation.

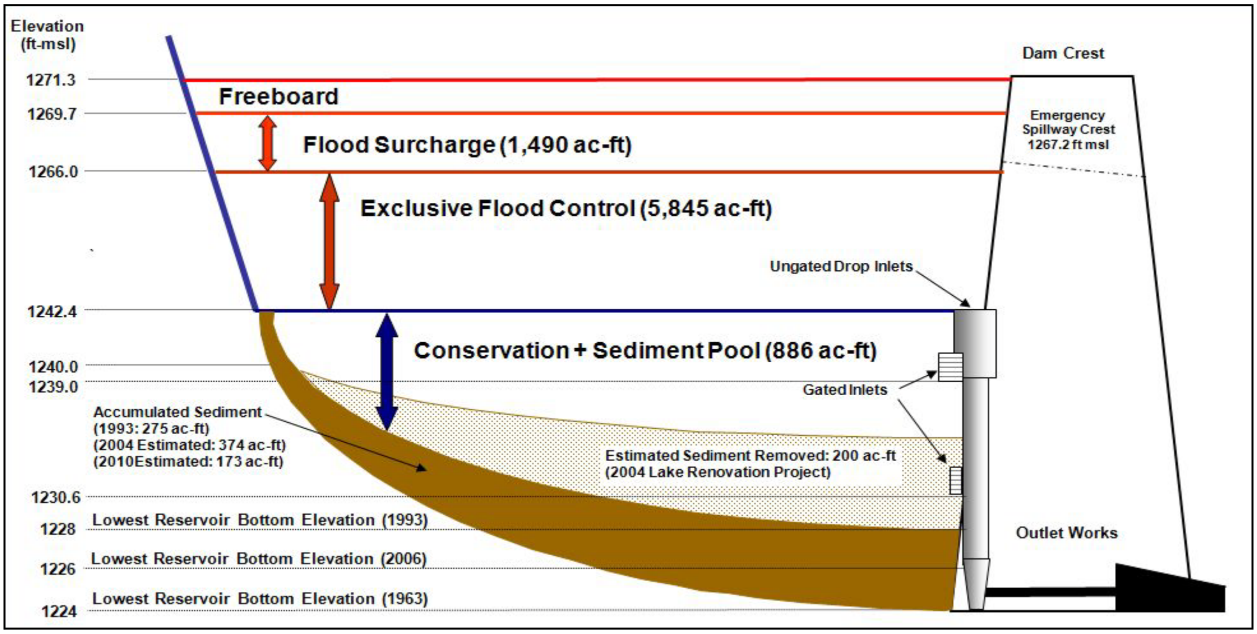

Figure 6.24. Current storage zones of Holmes Reservoir based on the 2006 NGPC survey data, recently implemented lake renovation project, and estimated sedimentation**.**

6.2.5.1.5 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Holmes Reservoir since the late 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Figure 6.25 shows the location of the sites that have been monitored for water quality during the past 5 years (i.e., 2006 through 2010). The inflow runoff sites (HOLNFEST1 and HOLNFWST1) and the in-reservoir bacteria site (HOLLKBACT1) were sampled by the NDEQ. The other in-reservoir sites (HOLLKND1, HOLLKMLN1, HOLLKMLS1, and HOLLKUP1) were sampled by the District. The near-dam location (HOLLKND1) has been continuously monitored by the District since 1980.

Figure 6.25. Location of sites where water quality monitoring was conducted at Holmes Reservoir during the period 2006 through 2010.

6.2.5.2 <u>Water Quality in Holmes Reservoir</u>

6.2.5.2.1 Existing Water Quality Conditions

6.2.5.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Holmes Reservoir at sites HOLLKND1, HOLLKMLN1, and HOLLKMLS1 from May through September during the 5-year period 2006 through 2010 are summarized, respectively, in Plates 122 through 124. A review of these results indicated possible water quality concerns regarding dissolved oxygen, pH, selenium, and nutrients.

An appreciable number (>15%) of dissolved oxygen measurements throughout Holmes Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plates 122 - 124). All of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and may have been associated with thermal stratification. Nebraska's Water Quality Standards makes the following provision regarding the application of the State's water quality standards' criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen situation in Holmes Reservoir, and the low dissolved oxygen levels are not considered to be a water quality standards non-attainment situation.

An appreciable number (>18%) of pH readings throughout Holmes Reservoir were above the numeric pH criteria of 9.0 for the protection of warmwater aquatic life (Plates 122 - 124). The measured pH values also exhibited a substantial range (i.e., 6.5 - 9.8). It is believed the highly variable pH values are associated with periods of high algal production and CO_2 uptake and release during photosynthesis and respiration. The initial high water clarity in Holmes Reservoir, attributed to the newly completed lake restoration project, has allowed for extensive algal production due to the depth of the photic zone and the availability of nutrients.

Nutrient criteria defined in Nebraska's water quality standards for R14 impounded waters include: total phosphorus (50 ug/l), total nitrogen (1,000 ug/l), and chlorophyll *a* (10 ug/l). All three of these criteria were exceeded in Holmes Reservoir (Plates 122 -124). The total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 94, 69, and 73 percent of the samples collected at site HOLLKND1. All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" (i.e., May through September) and the reported mean values represent the growing season average for the 5-year period 2006 through 2010. Based on the State of Nebraska's impairment assessment methodology, the mean value for total phosphorus and the percent exceedence of the upper pH criterion (Plate 122) may indicate impairment of the Aquatic Life and Aesthetics beneficial uses of Holmes Reservoir due to nutrients.

Due to the recent lake renovation project, Nebraska's water quality standards place Holmes Reservoir in category 4R. Nutrient assessment of category 4R designated waters may be misleading due to the trophic upsurge which can occur when the reservoir is refilled. This upsurge is typically followed by a period of trophic decline. Reservoirs may be designated as category 4R for a period of up to 8 years.

6.2.5.2.1.2 Thermal Stratification

6.2.5.2.1.2.1 <u>Longitudinal Temperature Contour Plots</u>

Late-spring and summer thermal conditions of Holmes Reservoir measured during 2009 and 2010 are depicted by longitudinal temperature contour plots constructed along the length of the north arm of the reservoir. Plates 125 and 126, respectively, provide longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites HOLLKND1, HOLLKMLN1, and HOLLKUP1 in 2009 and 2010. These temperature plots indicate that Holmes Reservoir exhibited periodic thermal stratification during the summer. The maximum difference monitored between the surface and bottom water temperatures during the 2-year period was 7°C in July of 2010 (Plate 126).

6.2.5.2.1.2.2 Near-Dam Temperature Depth-Profile Plots

Existing summer thermal stratification of Holmes Reservoir, at the deep water area near the dam, measured over the 5-year period 2006 through 2010 is depicted by depth-profile temperature plots (Plate 127). The depth-profile temperature plots indicate that the reservoir periodically exhibited significant summer thermal stratification over the past 5 years. Since Holmes Reservoir ices over in the winter and seemingly exhibits periodic circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.2.5.2.1.3 Summer Dissolved Oxygen Conditions

6.2.5.2.1.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Holmes Reservoir through the north arm based on depth-profile measurements taken during 2009 and 2010 at sites HOLLKND1, HOLLKMLN1, and HOLLKUP1. Plates 128 and 129, respectively, provide longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored along the reservoir bottom near the dam in both years (Plates 128 and 129). Super saturation of dissolved oxygen was also monitored in shallow water areas (Plates 128 and 129). Dissolved oxygen supersaturation was attributed to high rates of photosynthesis by aquatic vegetation in the reservoir during the day (see discussion of pH monitoring in Section 6.1.5.2.1.4.2).

6.2.5.2.1.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

Existing summer dissolved oxygen conditions in Holmes Reservoir are described by the dissolved oxygen depth-profiles measured near the dam over the 5-year period 2006 through 2010. Summer depth-profile dissolved oxygen plots were compiled for the 5 years (Plate 130). On most occasions there was a significant vertical gradient in summer dissolved oxygen levels. Although Holmes Reservoir appears to be polymictic based on thermal stratification, there appears to be enough inhibition to mixing to allow hypoxic conditions to develop near the reservoir bottom in the area near the dam.

6.2.5.2.1.3.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of Holmes Reservoir with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2009 and 2010 and the NGPC's current Area-Capacity Tables (2006 Survey) for the reservoir. The constructed contour plots were reviewed to identify the "worst-case" dissolved oxygen condition. The "worst-case" condition was taken to be the contour plot with the highest elevations of the 5 mg/l and 2.5 mg/l dissolved oxygen isopleths. The July 15, 2010 contour plot indicates a pool elevation of 1244.6 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1238.0 ft msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1236.0 ft-msl (Plate 129). The NGPC Area-Capacity Tables give storage capacities of 1,102 ac-ft for elevation 1244.6 ft-msl,

342 ac-ft for elevation 1238.0 ft-msl, and 171 ac-ft for elevation 1236.0 ft-msl. On July 15, 2010 it is estimated that 31 percent of the volume of Holmes Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 16 percent of the reservoir volume was hypoxic.

6.2.5.2.1.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in Holmes Reservoir indicated hypoxic conditions were present during the summers of 2009 and 2010, longitudinal contour and depth-profile plots were constructed for ORP and pH. Near-surface and near-bottom water quality samples collected when hypoxia was present were also compared.

6.2.5.2.1.4.1 Oxidation-Reduction Potential

Plates 131 and 132, respectively, provide longitudinal ORP contour plots based on depth-profile measurements taken in 2009 and 2010. The ORP values indicated somewhat reduced conditions occasionally occurred near the bottom of Holmes Reservoir in both years. Plate 133 plots depth profiles for ORP measured during the summer over the past 5 years in the deep water area of Holmes Reservoir near the dam. ORP values approaching 0 mV occasionally occur near the bottom of Holmes Reservoir during the summer. However, given the polymictic nature of the reservoir these conditions seemingly are not long lasting (Plate 133).

6.2.5.2.1.4.2 pH

Longitudinal contour plots for pH conditions measured in 2009 and 2010 are provided, respectively, in Plates 134 and 135. Plate 136 plots depth profiles for pH measured during the summer over the past 5 years in the deep water area of Holmes Reservoir near the dam. An appreciable vertical gradient in pH regularly occurred in the reservoir during the summer (Plates 134 - 136). It appears occasional reduced conditions in the deeper water of Holmes Reservoir seemingly lead to in lower pH levels near the reservoir bottom. The lowest measured pH levels near the reservoir bottom were above the lower pH criterion of 6.5 for the protection of warmwater aquatic life. A more significant concern appears to be high pH levels in “shallow” water areas of the reservoir. The highest measured pH levels were above the upper pH criterion of 9.0 for the protection of warmwater aquatic life. In August of 2010 over half of the volume of Holmes Reservoir exceeded a pH level of 9, and in September of 2009 and July of 2010 nearly half exceeded the pH criterion (Plates 134 and 135). The high pH levels are attributed to high rates of photosynthesis by aquatic vegetation and the associated uptake of carbon dioxide in the reservoir during the day.

6.2.5.2.1.4.3 Comparison of Near-Surface and Near-Bottom Water Quality Conditions

Paired near-surface and near-bottom water quality samples collected from Holmes Reservoir during the summer when hypoxia was present were compared (Plate 137). Near-surface conditions were represented by samples collected within 1-meter of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site HOLLKND1 during the 5-year period 2006 through 2010. During the 5-year period a total of 25 paired samples were collected monthly from May through September. Of the 25 paired samples collected, eleven (44%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature (11), dissolved oxygen (11), oxidation-reduction potential (11), pH (11), alkalinity (11), total ammonia (11), nitrate-nitrate nitrogen (11), total phosphorus (11), and orthophosphorus (11) (Plate 137)

[Note: the number in parentheses is the number of paired observations available for each parameter]. A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were not significantly different for nitrate-nitrite nitrogen, total alkalinity, total phosphorus, or ortho-phosphorus. Parameters that were significantly lower in the near-bottom water of Holmes Reservoir when hypoxia was present included: water temperature ($p < 0.0001$), dissolved oxygen ($p < 0.0001$), ORP ($p < 0.005$), and pH ($p < 0.0001$). Parameters that were significantly higher in the near-bottom water included: total ammonia ($p < 0.01$) and total phosphorus ($p < .05$).

6.2.5.2.1.5 Water Clarity

6.2.5.2.1.5.1 <u>Secchi Transparency</u>

Figure 6.26 displays a box plot of the Secchi depth transparencies measured at the four in-reservoir monitoring sites (i.e., HOLLKND1, HOLLKMLN1, HOLLKMLS1, and HOLLKUP1) from 2008 through 2010. The Secchi depth transparencies measured at all four sites were similar (Figure 6.26). The Secchi depth transparencies measured at Holmes Reservoir were the highest measured at any of the Salt Creek tributary reservoirs.

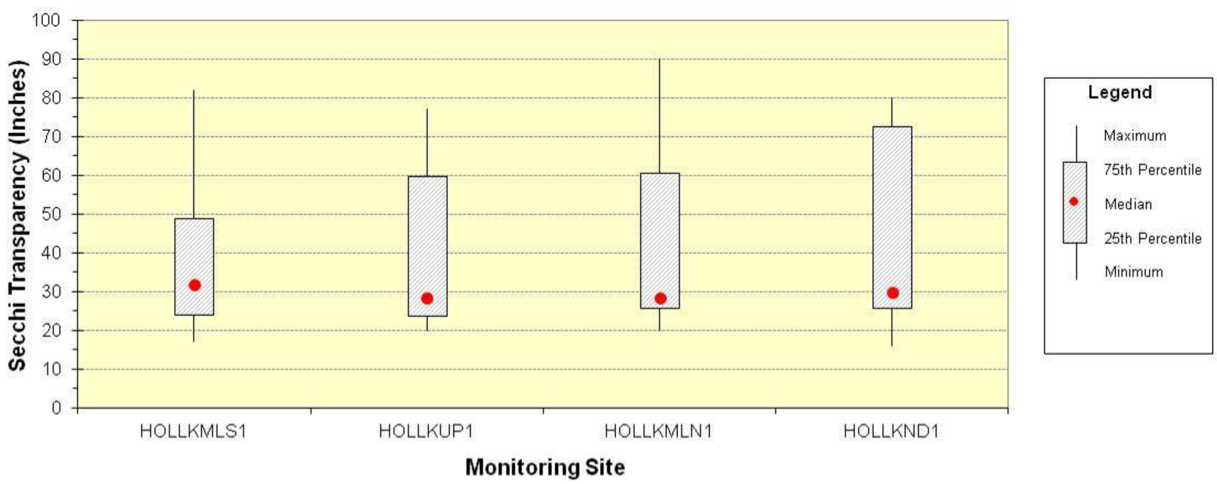

Figure 6.26. Box plot of Secchi depth transparencies measured in Holmes Reservoir from 2008 through 2010.

6.2.5.2.1.5.2 <u>Turbidity</u>

Turbidity contour plots were constructed along the length of Holmes Reservoir through the north arm based on depth-profile measurements taken during 2007 and 2008. Plates 138 and 139, respectively, provide longitudinal turbidity contour plots based on depth-profile measurements taken from May through September. The only longitudinal variability in turbidity occurred in July of 2010 when sampling occurred shortly after a summer rain. Some vertical variability in turbidity occurred that may have been attributable to phytoplankton (Plates 138 and 139).

6.2.5.2.1.6 Reservoir Trophic Status

Trophic State Index (TSI) values for Holmes Reservoir were calculated from monitoring data collected during the 5-year period 2006 through 2010 at the near-dam ambient monitoring site (i.e., HOLLKND1). Table 6.17 summarizes the TSI values calculated for the reservoir. The TSI values

indicate that the near-dam lacustrine area of Holmes Reservoir is in a eutrophic to slightly hypereutrophic condition.

Table 6.17. Summary of Trophic State Index (TSI) values calculated for Holmes Reservoir for the 5-year period 2006 through 2010.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	24	61	64	45	73
TSI(TP)	25	65	65	55	73
TSI(Chl)	25	70	72	50	87
TSI(Avg)	25	65	67	51	77

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values.
Note: See Section 4.1.3 for discussion of TSI calculation.

6.2.5.2.1.7 Monitoring at Swimming Beaches

A designated swimming beach is not located on Holmes Reservoir; however, the reservoir is used extensively for recreation (e.g., canoeing, kayaking, paddle-boating, wind surfing, etc.). Since these recreational uses can lead to direct contact with water, bacteria (i.e., *E. coli*) and microcystin monitoring were conducted by the NDEQ at the reservoir. During the 5-year period 2006 through 2010, bacteria and microcystin samples were collected weekly from May through September. The samples were collected from the reservoir near the marina on the north shore at site HOLLKBACT1 (Figure 6.25).

6.2.5.2.1.7.1 Bacteria Monitoring

Table 6.18 summarizes the results of the *E. coli* bacteria monitoring. The "running 5-week" geometric means were calculated as running geometric means for five consecutive weekly bacteria samples through the recreational season (i.e., May through September). The "pooled" geomean was determined by pooling all the weekly bacteria samples collected during the recreational season over the 5-year period and calculating a single geomean. All nondetects were set to 1 to calculate geomeans. The sampling results were compared to the following Nebraska water quality criteria for *E. coli* bacteria:

> *E. coli* bacteria should not exceed a geometric mean of 126/100ml. For increased confidence of the criteria, the geometric mean should be based on a minimum of five samples taken within a 30-day period. Single sample maximum allowable density for designated bathing beaches is 235/100ml.

The pooled geomean was compared to the State of Nebraska's impairment assessment criteria regarding the assessment of the Primary Contact Recreation beneficial use using *E. coli* bacteria data. Based on those criteria a Primary Contact Recreation use in Homes Reservoir is not impaired due to bacteria. The higher bacteria levels monitored in the reservoir are believed to be associated with runoff events.

Table 6.18. Summary of weekly (May through September) *E. coli* bacteria samples collected at Holmes Reservoir (i.e., site HOLLKBACT1) during the 5-year period 2006 through 2010**.**

***E. coli* – Individual Samples**		***E. coli* – Geomeans (Running 5-Week)**	
Number of Samples	102	Number of Geomeans	82
Mean (cfu/100ml)	121	Average	42
Median (cfu/100ml)	20	Median	26
Minimum (cfu/100ml)	1	Minimum	5
Maximum (cfu/100ml)	1,986	Maximum	192
Percent of samples exceeding 235/100ml	13%	Percent of Geomeans exceeding 126/100ml	6%
		***E. coli* – Geomean (5-Year Pooled)**	
		3-Year Pooled Geomean	25

6.2.5.2.1.7.2 Microcystin Monitoring

Table 6.19 summarizes the microcystin monitoring conducted at site HOLLKBACT1 on Holmes Reservoir during the 3-year period 2006 through 2010. These results were compared to the 20 ug/l criterion for issuing health advisories and the posting of swimming beaches. One sample (1%) exceeded the criterion. The monitored levels of microcystin do not indicate a significant cyanobacteria toxin concern at Holmes Reservoir.

Table 6.19. Summary of weekly (May through September) microcystin samples collected at Holmes Reservoir (i.e., site HOLLKBACT1) during the 5-year period 2006 through 2010.

Summary Statistic	Site HOLLKBACT1
Number of Samples	101
Minimum (ug/l)	n.d.
25th percentile (ug/l)	0.1
Median (ug/l)	0.5
75th Percentile (ug/l)	1.9
Maximum (ug/l)	26
Percent of samples exceeding 20 ug/l	1%

6.2.5.2.2 Water Quality Trends (1980 through 2008)

Water quality trends from 1980 to 2010 were determined for Holmes Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through October at the near-dam monitoring site (i.e., HOLLKND1). Plate 140 displays a scatter-plot of the collected data for the four parameters and linear regression lines for the period 1980 through 2002 and 2006 through 2010. The data gap of 2002 through 2005 is the period when the lake renovation project was implemented at Holmes Reservoir. The 2006 through 2010 monitoring data reflect conditions after implementation of the lake renovation project. As more "post-project" water quality data is collected, analyses for step trend assessment will be pursued to test for water quality changes from "pre-project" conditions. An anecdotal observational review of the "pre-project" and "post-project" scatter plots suggests that all four parameters improved immediately after the project implementation was completed (i.e., Secchi depths increased and total phosphorus, chlorophyll *a*, and TSI decreased). However, by the end of 2010 it appears that with the exception of Secchi depth, all other parameters had returned to near pre-project levels (Plate 140).

6.2.5.2.3 Existing Water Quality Conditions of Runoff Inflows to Holmes Reservoir

Existing water quality conditions in the main tributary inflows to Holmes Reservoir were monitored by the NDEQ under runoff conditions, during the period of April through September, at two sites HOLNFSTH1 and HOLNFEST1. Both sites were less than ¼ mile upstream from the reservoir (Figure 6.25). Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from "base-flow" conditions. Plates 141 and 142, respectively, summarize water quality conditions that were monitored at sites HOLNFSTH1 and HOLNFEST1 under runoff conditions during the 5-year period 2004 through 2008. Tributary inflows to Holmes Reservoir were not monitored in 2009 and 2010.

6.2.6 OLIVE CREEK RESERVOIR

6.2.6.1 Background Information

6.2.6.1.1 Project Overview

The dam forming Olive Creek Reservoir is located on a south tributary of Olive Branch of Salt Creek. The dam was completed on September 20, 1963 and the reservoir reached its initial fill on June 30, 1965. The Olive Creek Reservoir watershed is 8.2 square miles. The watershed was largely agricultural when the dam was built in 1963 and has remained so to the present time.

6.2.6.1.2 Aquatic Habitat Improvement and Water Quality Management Project

A lake renovation project was completed at Olive Creek Reservoir in 2002. The goal of the project was to reduce the quantity of both sediment and nutrients entering the reservoir; to reduce the likelihood of winter fish kills (oxygen depletion); to replace the rough fish dominated community with largemouth bass, bluegill, channel catfish and walleye; and to increase the quantity and quality of shoreline habitat for fish. Approximately $2 million in Federal, State, and Local funding was spent on the lake renovation project.

The lake renovation project consisted of two phases. Phase 1 included excavating approximately 138,000 cubic yards of sediment from the reservoir basin to construct six jetties, three islands, and two offshore breakwaters (see Figure 6.28). The structures collectively added 4,700 feet of shoreline, a 43 percent increase to the reservoir. In addition, shorelines and bays were reshaped and the outlet structure was modified to allow for minor water level manipulation, all as a means of enhancing aquatic vegetation. Phase 2 was the construction of four sediment basins, two spanning each of the two main inflowing streams (See Figure 6.28). The basins were created to intercept and slow silt laden runoff following rain events, thus allowing some of the sediment load to settle out before the water reached the main reservoir. Since these basins were located in the flood pool, they occupied flood storage space which had to be mitigated. This was accomplished by excavating an amount of material from behind the basins equal to the amount of space they and their impounded water occupied. The mitigation requirement reduced the reservoir basin excavation by a comparable amount. In addition to the work on the reservoir, other funding was utilized to help implement BMPs (best management practices) in the Olive Creek Reservoir watershed.

6.2.6.1.3 Olive Creek Dam Intake Structure

The dam intake at Olive Creek Dam is a drop inlet structure consisting of a single reinforced concrete box shaft. Its inside dimensions are 4 feet by 6 feet. The intake structure has four ungated openings – two 24” x 72” openings with a crest elevation at 1340.9 ft-msl and two 12” x 30” openings with a crest elevation at 1335.0 ft-msl. A 36” x 36” gated opening with a crest elevation of 1330.0 ft-msl was constructed into the upstream wall. As part of the recent lake renovation project a “stop-log” structure was attached to the concrete box shaft over the 36” x 36” gated opening. The 36” x 36” gate is permanently left open and pool levels are managed with the external stop-log structure. The purpose of the gate modification is to allow for better management of pool elevations for water quality and fishery management. The gated outlet may also be used to release water for downstream needs.

6.2.6.1.4 Reservoir Storage Zones

Figure 6.27 depicts the current storage zones of Olive Creek Reservoir based on the 1993 survey data, results of the recent lake renovation project, and estimated sedimentation. After accounting for the

sediment removed from the reservoir basin as part of the recent lake renovation project, it is estimated that 17 to 21 percent of the "as-built" volume to the top of the Conservation Pool has been lost to sedimentation as of 2010. The annual volume loss is estimated to be 0.51 percent. Based on the State of Nebraska's impairment assessment methodology, these values indicate that Olive Creek Reservoir's water quality dependent uses are not at this time impaired due to sedimentation.

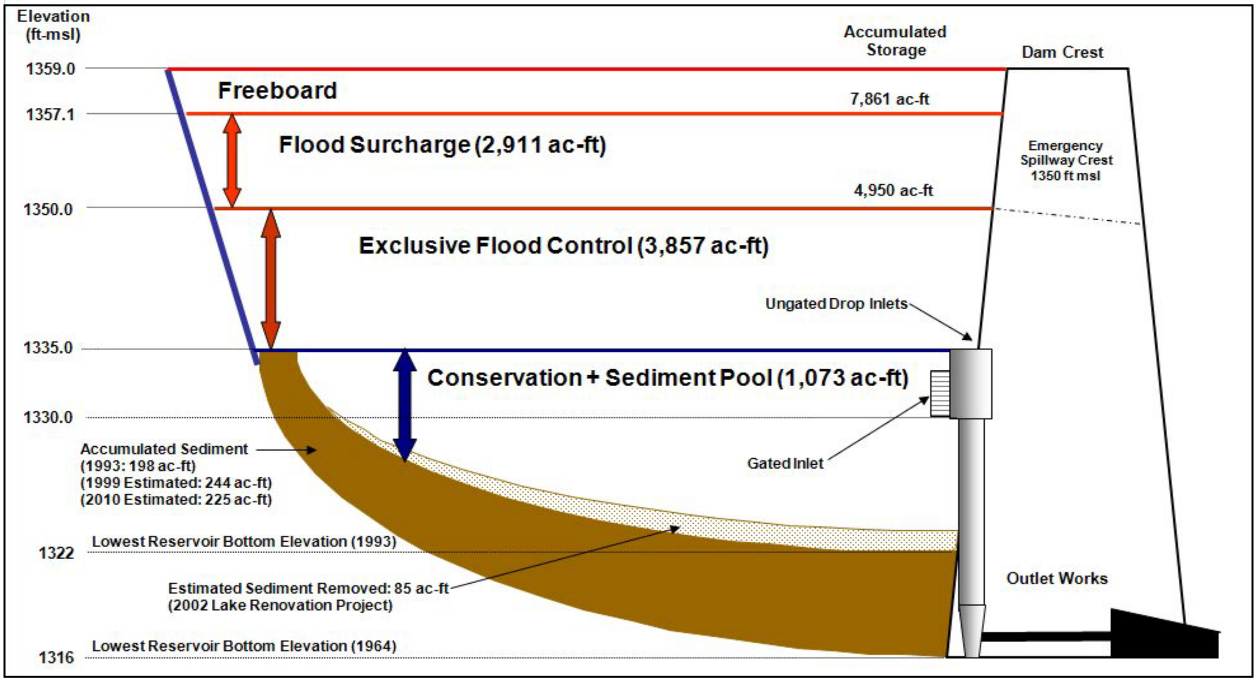

Figure 6.27. Current storage zones of Olive Creek Reservoir based on the 1993 survey data, recently implemented lake renovation project, and estimated sedimentation.

6.2.6.1.5 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Olive Creek Reservoir since the late 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Figure 6.28 shows the location of the sites that have been monitored for water quality during the past 5 years (i.e., 2006 through 2010). The inflow runoff sites (OCRNFWST1 and OCRNFEST1) were sampled by the NDEQ. The other in-reservoir sites (OCRLKND1, OCRLKML1, and OCRLKUP1) were sampled by the District. The near-dam location (OCRLKND1) has been continuously monitored by the District since 1980.

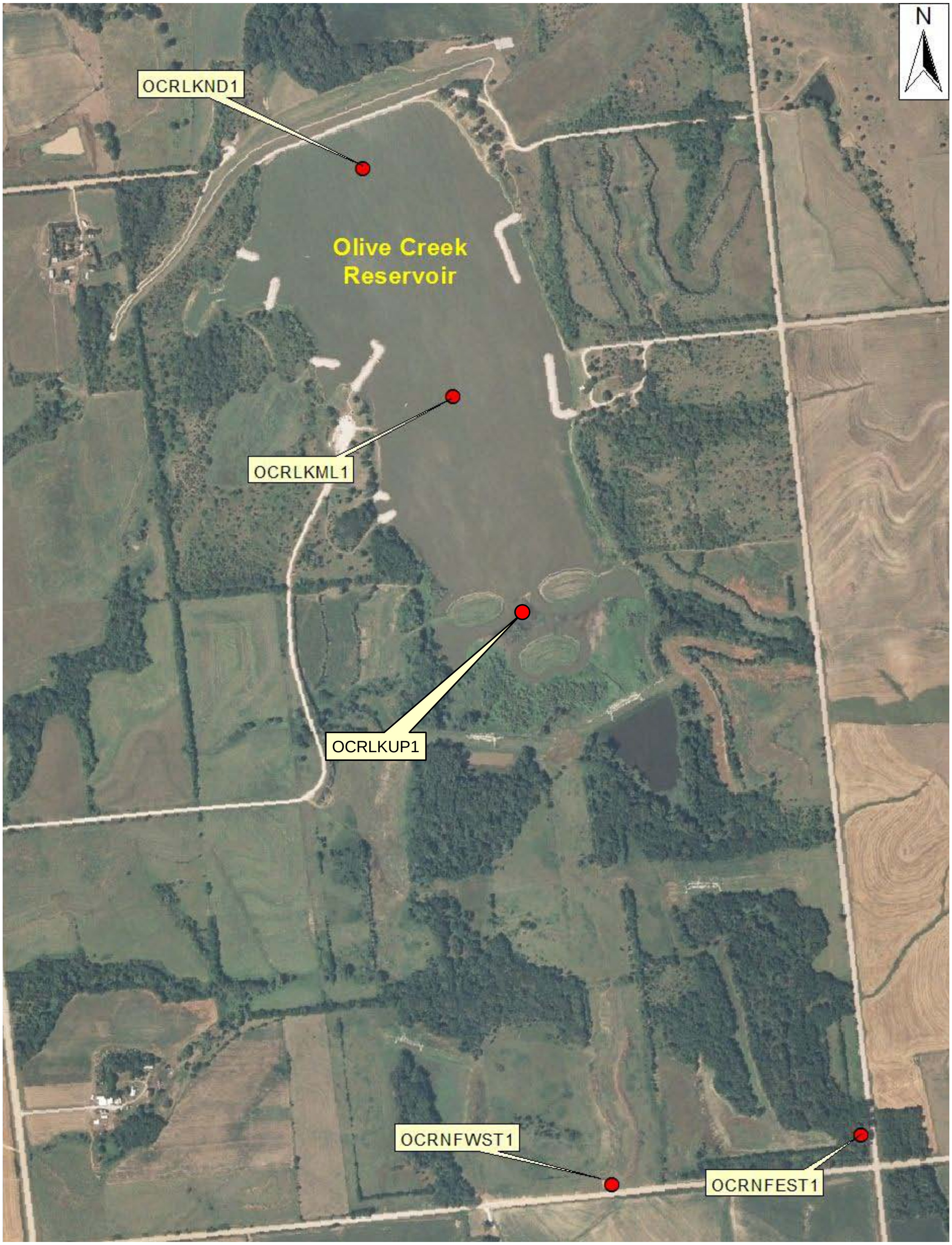

Figure 6.28. Location of sites where water quality monitoring was conducted at Olive Creek Reservoir during the period 2006 through 2010.

6.2.6.2 Water Quality in Olive Creek Reservoir

6.2.6.2.1 Existing Water Quality Conditions

6.2.6.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Olive Creek Reservoir at sites OCRLKND1 and OCRLKML1 from May through September during the 5-year period 2006 through 2010 are summarized, respectively, in Plates 143 and 144. A review of these results indicated possible water quality concerns regarding dissolved oxygen, pH, ammonia, arsenic, selenium, and nutrients.

An appreciable number (>14%) of dissolved oxygen measurements throughout Olive Creek Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plates 143- 144). All of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and may have been associated with thermal stratification. Nebraska's Water Quality Standards makes the following provision regarding the application of the State's water quality standards' criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision may apply to the low dissolved oxygen situation in Olive Creek Reservoir. However, given the shallow depth of Olive Creek Reservoir, the reservoir rarely exhibits significant thermal stratification during the summer (Plates 145 - 146). Thus, natural thermal stratification may not exclude any applicable narrative and numeric water quality standards criteria. The lower dissolved oxygen levels indicate a possible water quality standards non-attainment situation.

A large number (>39%) of pH readings throughout Olive Creek Reservoir were above the numeric pH criteria of 9.0 for the protection of warmwater aquatic life (Plates 143 and 144). The greatest pH value measured was 9.9 SU. The magnitude and number of pH criterion exceedences indicate a noteworthy water quality concern. Based on the State of Nebraska's impairment assessment criteria, the percent exceedence of the upper pH criterion indicates impairment of the Aquatic Life beneficial use of Olive Creek Reservoir. It is believed the high pH values may be associated with periods of high algal production and CO_2 uptake during photosynthesis.

The chronic ammonia criterion for the protection of warmwater aquatic life was seemingly exceeded in 6 percent of the 47 samples collected from Olive Creek Reservoir in the area near the dam (Plate 143). Ammonia criteria are pH and temperature dependant, and the criteria cited are based on median values that may or may not represent conditions when the higher ammonia occurred.

The chronic arsenic criterion for the protection of warmwater aquatic life was exceeded in 3 of the 5 samples collected from Olive Creek Reservoir in the area near the dam (Plate 143). Based on the State of Nebraska's impairment assessment methodology, the percent exceedence of the chronic arsenic criterion indicates impairment of the Aquatic Life beneficial use of Olive Creek Reservoir.

One of five selenium measurements (20%) exceeded the acute and chronic criteria for the protection of aquatic life. At this time the exceedence is considered to be a possible outlier.

Nutrient criteria defined in Nebraska's water quality standards for R13 impounded waters include: total phosphorus (50 ug/l), total nitrogen (1,000 ug/l), and chlorophyll *a* (10 ug/l). All three of these criteria were exceeded throughout Olive Creek Reservoir (Plates 143 and 144). The total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 100, 95, and 76 percent of the samples collected at site OCRLKND1. All the samples were collected during the "growing

season" (i.e., May through September) and the reported mean values represent the growing season average for the 5-year period 2006 through 2010. Based on the State of Nebraska's impairment assessment criteria, the mean values for the three parameters (Plate 143) indicate impairment of the Aquatic life beneficial use of Olive Creek Reservoir due to nutrients.

6.2.6.2.1.2 Thermal Stratification

6.2.6.2.1.2.1 Longitudinal Temperature Contour Plots

Late-spring and summer thermal conditions of Olive Creek Reservoir measured during 2009 and 2010 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plates 145 and 146, respectively, provide longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites OCRLKND1, OCRLKML1, and OCRLKUP1 in 2009 and 2010. These temperature plots indicate that Olive Creek Reservoir rarely exhibited significant thermal stratification during the 2-year period. The maximum difference monitored between the surface and bottom water temperatures during the 2-year period was 4°C in June of 2009 (Plate 145).

6.2.6.2.1.2.2 Near-Dam Temperature Depth-Profile Plots

Existing summer thermal stratification of Olive Creek Reservoir, at the deep water area near the dam, measured over the 5-year period 2006 through 2010 is depicted by depth-profile temperature plots (Plate 147). The depth-profile temperature plots indicate that the reservoir rarely exhibited significant summer thermal stratification over the past 5 years. Since Olive Creek Reservoir ices over in the winter and seemingly exhibits periodic circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.2.6.2.1.3 Summer Dissolved Oxygen Conditions

6.2.6.2.1.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Olive Creek Reservoir based on depth-profile measurements taken during 2009 and 2010 at sites OCRLKND1, OCRLKML1, and OCRLKUP1. Plates 148 and 149, respectively, provide longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September in 2009 and 2010. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored on two occasions (June, 2009 and August, 2010) near the reservoir bottom near the dam (Plates 148 and 149). Super saturation of dissolved oxygen was also monitored in shallow water areas (Plate149). Dissolved oxygen supersaturation was attributed to high rates of photosynthesis by aquatic vegetation in the reservoir during the day (see discussion of pH monitoring in Section 6.1.5.2.1.4.2).

6.2.6.2.1.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

Existing summer dissolved oxygen conditions in Olive Creek Reservoir are described by the dissolved oxygen depth-profiles measured near the dam over the 5-year period 2006 through 2010. Summer depth-profile dissolved oxygen plots were compiled for the 5 years (Plate 150). On several occasions there was a significant vertical gradient in summer dissolved oxygen levels. Although Olive Creek Reservoir appears to be polymictic based on thermal stratification, there appears to be enough inhibition to mixing to allow hypoxic conditions to occasionally develop near the reservoir bottom.

6.2.6.2.1.3.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of Olive Creek Reservoir with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2009 and 2010 and the District's current Area-Capacity Tables (1993 Survey) for the reservoir. The constructed contour plots were reviewed to identify the "worst-case" dissolved oxygen condition. The "worst-case" condition was taken to be the contour plot with the highest elevations of the 5 mg/l and 2.5 mg/l dissolved oxygen isopleths. The June 18, 2009 contour plot indicates a pool elevation of 1332.9 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1325.5 ft msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1325.0 ft-msl (Plate 148). The District's Area-Capacity Tables give storage capacities of 787 ac-ft for elevation 1332.9 ft-msl, 117 ac-ft for elevation 1325.5 ft-msl, and 91 ac-ft for elevation 1325.0 ft-msl. On June 18, 2009 it is estimated that 15 percent of the volume of Olive Creek Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 12 percent of the reservoir volume was hypoxic.

6.2.6.2.1.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in Olive Reservoir indicated hypoxic conditions were present during the summers of 2006 through 2010, longitudinal contour and depth-profile plots were constructed for ORP and pH. Near-surface and near-bottom water quality samples collected when hypoxia was present were also compared.

6.2.6.2.1.4.1 Oxidation-Reduction Potential

Plates 151 and 152, respectively, provide longitudinal ORP contour plots based on depth-profile measurements taken in 2009 and 2010. The ORP values indicated "slightly" reduced conditions occurred on one occasion (July of 2010) in a small area near the dam of Olive Creek Reservoir (Plate 152). Plate 153 plots depth profiles for ORP measured during the summer over the past 5 years in the deep water area of Olive Creek Reservoir near the dam. The ORP depth profiles indicate that appreciable reduced conditions rarely occur in Olive Creek Reservoir during the summer (Plate 153).

6.2.6.2.1.4.2 pH

Longitudinal contour plots for pH conditions measured in 2009 and 2010 are provided, respectively, in Plates 154 and 155. Plate 156 plots depth profiles for pH measured during the summer over the past 5 years in the deep water area of Olive Creek Reservoir near the dam. High pH levels regularly occurred in the reservoir during the summer (Plates 154- 156). The highest measured pH levels were above the upper pH criterion of 9.0 for the protection of warmwater aquatic life. In June 2009 portions of Olive Creek Reservoir seemingly exceeded a pH level of 9. In July and August 2010 almost all of Olive Creek Reservoir seemingly exceeded a pH level of 9 (Plates 154 and 155). The high pH levels are attributed to high rates of photosynthesis by aquatic vegetation and the associated uptake of carbon dioxide in the reservoir during the day.

6.2.6.2.1.4.3 Comparison of Near-Surface and Near-Bottom Water Quality Conditions

Paired near-surface and near-bottom water quality samples collected from Olive Creek Reservoir during the summer when hypoxia was present were compared. Near-surface conditions were represented by samples collected within 1-meter of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site OCRLKND1 during the 5-year period 2006 through 2010. During the 5-year period a total of 25 paired samples were collected monthly from May through September. Of the 25 paired samples collected, 5 (20%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the

distribution of measured water quality conditions for the following parameters: water temperature (5), dissolved oxygen (5), oxidation-reduction potential (5), pH (5), alkalinity (4), total ammonia (4), nitrate-nitrate nitrogen (4), total phosphorus (4), and orthophosphorus (4) (Plate 157) *[Note: the number in parentheses is the number of paired observations available for each parameter]*. A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were not significantly different for oxidation-reduction potential, total ammonia, nitrate-nitrite nitrogen, total alkalinity, total phosphorus, or ortho-phosphorus. Parameters that were significantly lower in the near-bottom water of Olive Creek Reservoir when hypoxia was present included: water temperature ($p < 0.05$), dissolved oxygen ($p < 0.01$) and pH ($p < 0.01$).

6.2.6.2.1.5 Water Clarity

6.2.6.2.1.5.1 <u>Secchi Transparency</u>

Figure 6.29 displays a box plot of the Secchi depth transparencies measured at the three in-reservoir monitoring sites (i.e., OCRLKND1, OCRLKML1, and OCRLKUP1) from 2008 through 2010 (note: the monitoring sites are oriented in an upstream to downstream direction). The Secchi depth transparencies measured in Olive Creek Reservoir were similar at all three sites (Figure 6.29).

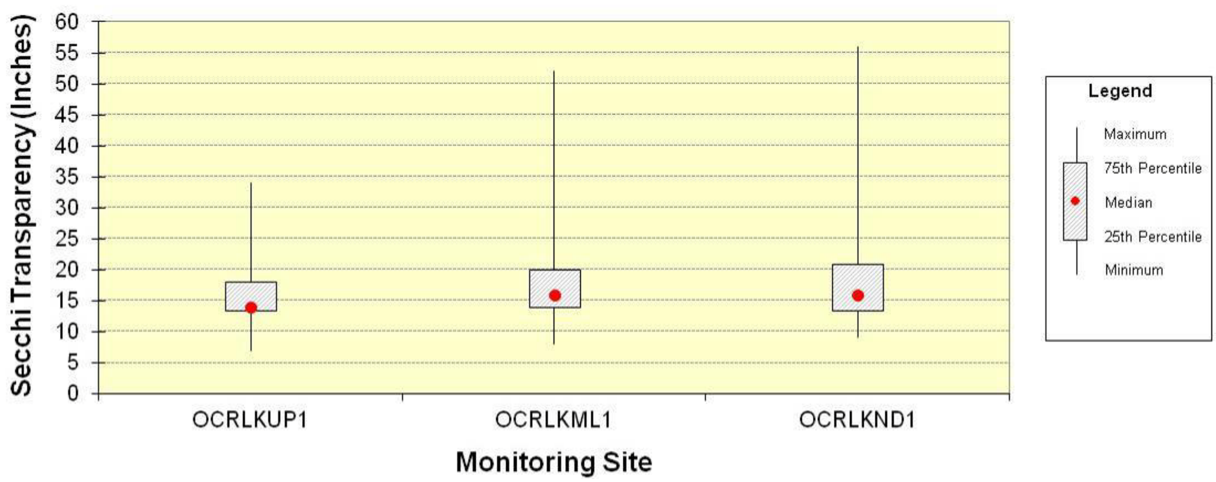

Figure 6.29. Box plot of Secchi depth transparencies measured in Olive Creek Reservoir 2008 through 2010. (Note: monitoring sites are oriented on the x-axis in an upstream to downstream direction.)**.**

6.2.6.2.1.5.2 <u>Turbidity</u>

Turbidity contour plots were constructed along the length of Olive Creek Reservoir based on depth-profile measurements taken during 2009 and 2010. Plates 158 and 159, respectively, provide longitudinal turbidity contour plots based on depth-profile measurements taken from May through September (Plates 158 and 159). Olive Creek Reservoir commonly exhibited longitudinal and depth variability in turbidity.

6.2.6.2.1.6 Reservoir Trophic Status

Trophic State Index (TSI) values for Olive Creek Reservoir were calculated from monitoring data collected during the 5-year period 2006 through 2010 at the near-dam ambient monitoring site (i.e., OCRLKND1). Table 6.20 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Olive Creek Reservoir is in a hypereutrophic condition.

Table 6.20. Summary of Trophic State Index (TSI) values calculated for Olive Creek Reservoir for the 5-year period 2006 through 2010.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	25	73	74	55	83
TSI(TP)	25	75	75	68	85
TSI(Chl)	25	72	74	40	89
TSI(Avg)	25	74	74	61	81

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values.

Note: See Section 4.1.3 for discussion of TSI calculation.

6.2.6.2.2 Water Quality Trends (1980 through 2010)

Water quality trends from 1980 to 2010 were determined for Olive Creek Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through October at the near-dam monitoring site (i.e., OCRLKND1). Plate 160 displays a scatter-plot of the collected data for the four parameters and a monotonic linear regression lines for the periods 1980 through 1998 and 2003 through 2010. The data gap of 1999 through 2002 is the period when the lake renovation project was implemented at Olive Creek Reservoir. When several years of post-project data has been collected, analyses for step trend assessment will be pursued to test for water quality changes from "pre-project" conditions (Plate 160). A cursory assessment of trend lines indicates post-project increases in water transparency, chlorophyll *a*, and trophic condition with a slight decrease in total phosphorus.

6.2.6.2.3 Existing Water Quality Conditions of Runoff Inflows to Olive Creek Reservoir

Existing water quality conditions in the main tributary inflows to Olive Creek Reservoir were monitored by the NDEQ under runoff conditions, during the period of April through September, at two sites OCRNFWST1 and OCRNFEST1 (Figure 6.28). Both sites were about ½ mile upstream from the reservoir. Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from "base-flow" conditions. Plate 161 and 162, respectively, summarize water quality conditions that were monitored at sites OCRNFWST1 and OCRNFEST1 under runoff conditions during the 5-year period 2004 through 2008. Tributary inflows to Olive Creek Reservoir were not monitored in 2009 and 2010.

6.2.7 PAWNEE RESERVOIR

6.2.7.1 <u>Background Information</u>

6.2.7.1.1 Project Overview

The dam forming Pawnee Reservoir is located on North Middle Creek. The dam was completed on July 16, 1964 and the reservoir reached its initial fill on June 21, 1967. The Pawnee Reservoir watershed is 35.9 square miles. The watershed was largely agricultural when the dam was built in 1964 and has remained so to the present time.

6.2.7.1.2 Pawnee Dam Intake Structure

The Pawnee Dam intake structure is a single reinforced concrete box shaft commonly called a drop inlet structure. Its inside dimensions are 5 feet by 10 feet. The intake structure has two ungated openings, each 34" x 120" with crest elevations at 1244.3 ft-msl. A 42" x 60" gated opening was constructed into the upstream wall of the inlet structure at a crest elevation of 1236.0 ft-msl. The purpose of the gated opening is to lower the level of the conservation pool in order to inspect the conduit, make shoreline repairs, and manage fish populations.

6.2.7.1.3 Reservoir Storage Zones

Figure 6.30 depicts the current storage zones of Pawnee Reservoir based on the 1991 survey data and estimated sedimentation. It is estimated that 24 to 25 percent of the "as-built" volume to the top of the Conservation Pool has been lost to sedimentation as of 2010. The annual volume loss is estimated to be 0.53 percent. Based on the State of Nebraska's impairment assessment criteria, these values indicate that Pawnee Reservoir's water quality dependent uses are impaired due to sedimentation at this time.

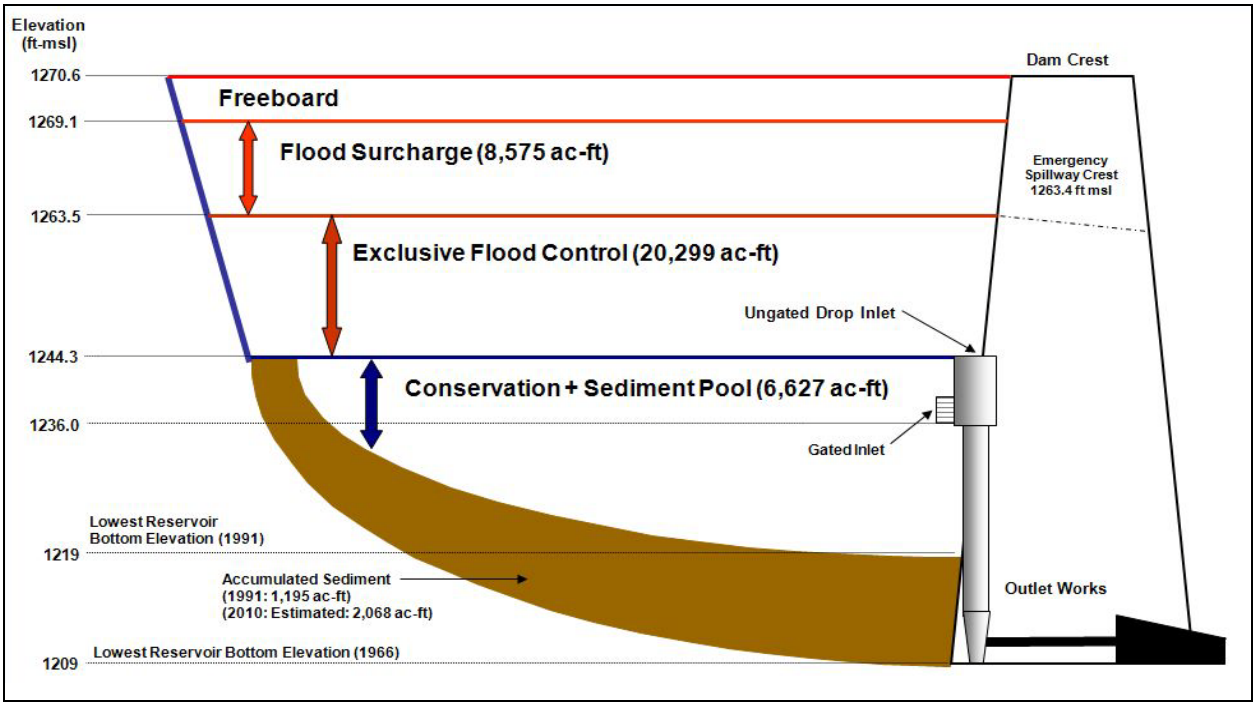

Figure 6.30. Current storage zones of Pawnee Reservoir based on the 1991 survey data and estimated sedimentation**.**

6.2.7.1.4 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Pawnee Reservoir since the late 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Figure 6.31 shows the location of the sites that have been monitored for water quality during the 5-year period 2006 through 2010. The inflow runoff site (PAWNF1) and bacteria sites (PAWLKBACT1 and PAWLKBACT2) were sampled by the NDEQ. The other in-reservoir sites (PAWLKND1, PAWLKML1, and PAWLKUP1) were sampled by the District. The near-dam location (PAWLKND1) has been continuously monitored by the District since 1980.

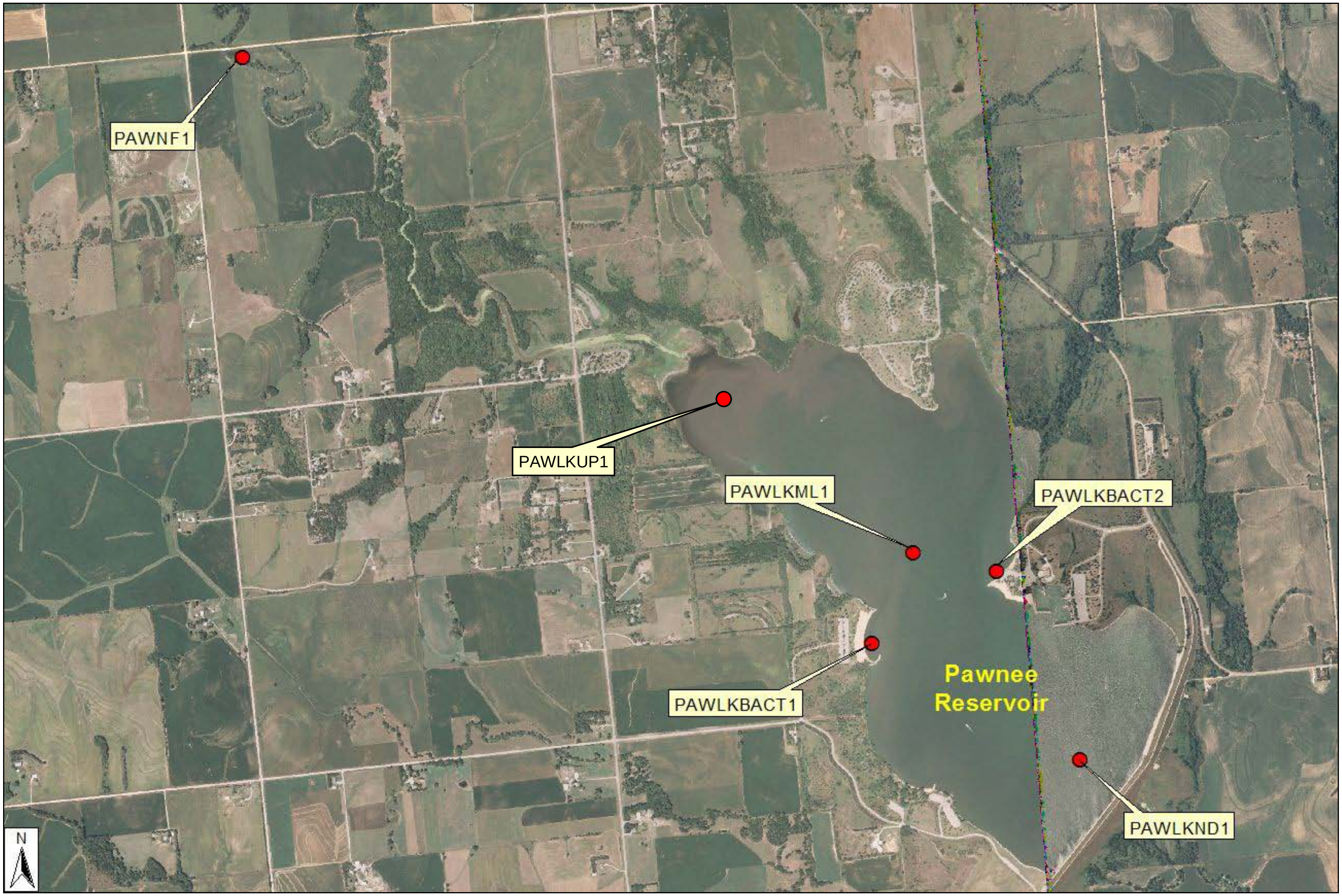

Figure 6.31. Location of sites where water quality monitoring was conducted at Pawnee Reservoir during the period 2006 through 2010.

6.2.7.2 Water Quality in Pawnee Reservoir

6.2.7.2.1 Existing Water Quality Conditions

6.2.7.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Pawnee Reservoir at sites PAWLKND1 and PAWLKML1 from May through September during the 5-year period 2006 through 2010 are summarized, respectively, in Plates 163 and 164. A review of these results indicated possible water quality concerns regarding dissolved oxygen, pH, ammonia, selenium, and nutrients.

An appreciable number (>10%) of dissolved oxygen measurements in Pawnee Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plates 163 and 164). Most of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and may have been associated with a slight thermal stratification. Nebraska's Water Quality Standards makes the following provision regarding the application of the State's water quality standards' criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen situation in Pawnee Reservoir, and the measured dissolved oxygen levels below 5 mg/l may not be a water quality standards non-attainment situation.

An appreciable number (>9%) of pH readings throughout Pawnee Reservoir were above the numeric pH criteria of 9.0 for the protection of warmwater aquatic life (Plates 163 and 164). The greatest pH value measured was 9.6 SU. Based on the State of Nebraska's impairment assessment criteria, the percent exceedence of the upper pH criterion indicates impairment of the Aquatic Life beneficial use of Pawnee Reservoir. It is noted that all of the high pH readings occurred when super-saturation of dissolved oxygen was monitored in the reservoir. It is believed the high pH values are associated with periods of high algal production and CO_2 uptake during photosynthesis.

The chronic ammonia criterion for the protection of warmwater aquatic life was seemingly exceeded in 4 percent of the 50 samples collected from Pawnee Reservoir in the area near the dam (Plate 163). Ammonia criteria are pH and temperature dependant, and the criteria cited are based on median values that may or may not represent conditions when the higher ammonia occurred.

One of five selenium measurements (20%) exceeded the chronic criterion for the protection of aquatic life. At this time the exceedence is considered to be a possible outlier.

Nutrient criteria defined in Nebraska's water quality standards for R13 impounded waters include: total phosphorus (50 ug/l), total nitrogen (1,000 ug/l), and chlorophyll *a* (10 ug/l). All three of these criteria were exceeded throughout Pawnee Reservoir (Plates 163 and 164). The total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 92, 92, and 80 percent of the samples collected at site PAWLKND1. All the samples were collected during the "growing season" (i.e., May through September) and the reported mean values represent the growing season average for the 5-year period 2006 through 2010. Based on the State of Nebraska's impairment assessment criteria, the mean values for the three parameters (Plate 163) indicate impairment of the Aquatic Life use of Pawnee Reservoir due to nutrients.

6.2.7.2.1.2 Thermal Stratification

6.2.7.2.1.2.1 Longitudinal Temperature Contour Plots

Late-spring and summer thermal conditions of Pawnee Reservoir measured during 2009 and 2010 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plates 165 and 166, respectively, provide longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites PAWLKND1, PAWLKML1, and PAWLKUP1 in 2009 and 2010. These temperature plots indicate that Pawnee Reservoir rarely exhibited significant thermal stratification during the 2-year period. The maximum difference monitored between the surface and bottom water temperatures during the 2-year period was 5°C in July of 2009 (Plate 165).

6.2.7.2.1.2.2 Near-Dam Temperature Depth-Profile Plots

Existing summer thermal stratification of Pawnee Reservoir, at the deep water area near the dam, measured over the 5-year period 2006 through 2010 is depicted by depth-profile temperature plots (Plate 167). The depth-profile temperature plots indicate that the reservoir rarely exhibited significant summer thermal stratification over the past 5 years. Since Pawnee Reservoir ices over in the winter and seemingly exhibits periodic circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.2.7.2.1.3 Summer Dissolved Oxygen Conditions

6.2.7.2.1.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Pawnee Reservoir based on depth-profile measurements taken during 2009 and 2010 at sites PAWLKND1, PAWLKML1, and PAWLKUP1. Plates 168 and 169, respectively, provide longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September in 2009 and 2010. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored on four occasions (July and September 2009, July and August 2010) near the reservoir bottom near the dam (Plates 168 and 169). Super-saturation of dissolved oxygen was also monitored in shallow water areas (Plate 168). Dissolved oxygen supersaturation was attributed to high rates of photosynthesis by aquatic vegetation in the reservoir during the day (see discussion of pH monitoring in Section 6.1.5.2.1.4.2).

6.2.7.2.1.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

Existing summer dissolved oxygen conditions in Pawnee Reservoir are described by the dissolved oxygen depth-profiles measured near the dam over the 5-year period 2006 through 2010. Summer depth-profile dissolved oxygen plots were compiled and plotted for the 5 years (Plate 170). On several occasions there was a significant vertical gradient in summer dissolved oxygen levels. Although Pawnee Reservoir appears to be polymictic based on thermal stratification, there appears to be enough inhibition to mixing to allow hypoxic conditions to occasionally develop near the reservoir bottom.

6.2.7.2.1.3.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of Pawnee Reservoir with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2009 and 2010 and the District's current Area-Capacity Tables (1991 Survey) for the reservoir. The constructed contour plots were reviewed to identify the "worst-case" dissolved oxygen condition. The "worst-case" condition was taken to be the contour plot with the highest elevations of the 5 mg/l and 2.5 mg/l dissolved oxygen isopleths. The July 7, 2009 contour plot indicates a pool elevation of 1244.3 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1238.0 ft msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1234.5 ft-

msl (Plate 168). The District's Area-Capacity Tables give storage capacities of 7,500 ac-ft for elevation 1244.3 ft-msl, 3687 ac-ft for elevation 1238.0 ft-msl, and 2255 ac-ft for elevation 1234.5 ft-msl. On July 7, 2009 it is estimated that 49 percent of the volume of Pawnee Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 30 percent of the reservoir volume was hypoxic.

6.2.7.2.1.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in Pawnee Reservoir indicated hypoxic conditions were present during the summers of 2009 and 2010, longitudinal contour and depth-profile plots were constructed for ORP and pH. Near-surface and near-bottom water quality samples collected when hypoxia was present were also compared.

6.2.7.2.1.4.1 <u>Oxidation-Reduction Potential</u>

Plates 171 and 172, respectively, provide longitudinal ORP contour plots based on depth-profile measurements taken in 2009 and 2010. The ORP values indicated "slightly" reduced conditions occurred near the reservoir bottom on two of the four the occasions when hypoxic conditions were monitored (July 7, 2009 and August 11, 2010) (Plates 171 and 172). Plate 173 plots depth profiles for ORP measured during the summer over the past 5 years in the deep water area of Pawnee Reservoir near the dam. The ORP depth profiles indicate that appreciable reduced conditions rarely occur in Pawnee Reservoir during the summer (Plate 173).

6.2.7.2.1.4.2 <u>pH</u>

Longitudinal contour plots for pH conditions measured in 2009 and 2010 are provided, respectively, in Plates 174 and 175. Plate 176 plots depth profiles for pH measured during the summer over the past 5 years in the deep water area of Pawnee Reservoir near the dam. An appreciable vertical gradient in pH occasionally occurred in the reservoir during the summer (Plates 174 - 176). It appears occasional reduced conditions in the deeper water of Pawnee Reservoir seemingly lead to in lower pH levels near the reservoir bottom. The lowest measured pH levels near the reservoir bottom were above the lower pH criterion of 6.5 for the protection of warmwater aquatic life. A concern may be occasional high pH levels in "shallow" water areas of the reservoir. On August 11, 2010 monitoring indicated these areas of Pawnee Reservoir had a pH level above the upper pH criterion of 9.0 for the protection of warmwater aquatic life (Plate 175). It is believed the high pH values are associated with periods of high algal production and CO_2 uptake during photosynthesis.

6.2.7.2.1.4.3 <u>Comparison of Near-Surface and Near-Bottom Water Quality Conditions</u>

Paired near-surface and near-bottom water quality samples collected from Pawnee Reservoir during the summer when hypoxia was present were compared. Near-surface conditions were represented by samples collected within 1-meter of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site PAWLKND1 during the 5-year period 2006 through 2010. During the 5-year period a total of 25 paired samples were collected monthly from May through September. Of the 25 paired samples collected, 10 (40%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature, dissolved oxygen, oxidation-reduction potential, pH, alkalinity, total ammonia, nitrate-nitrate nitrogen, total phosphorus, and orthophosphorus (Plate 177) *[Note: all parameters had ten paired observations]*. A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for

the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were not significantly different for nitrate-nitrite nitrogen and total phosphorus. Parameters significantly higher in the near-bottom samples when hypoxia was present were total ammonia ($p < 0.005$), total alkalinity ($p < 0.05$), and ortho-phosphorus ($p < 0.05$). Parameters that were significantly lower in the near-bottom water of Pawnee Reservoir when hypoxia was present included water temperature ($p < 0.0005$), dissolved oxygen ($p < 0.0001$), oxidation-reduction potential ($p < 0.05$), and pH ($p < 0.0001$).

6.2.7.2.1.5 Water Clarity

6.2.7.2.1.5.1 <u>Secchi Transparency</u>

Figure 6.32 displays a box plot of the Secchi depth transparencies measured at the three in-reservoir monitoring sites (i.e., PAWLKND1, PAWLKML1, and PAWLKUP1) during 2010 (note: the monitoring sites are oriented in an upstream to downstream direction). The Secchi depth transparencies measured in the upper reaches of Pawnee Reservoir (i.e., site PAWLKUP1) were significantly lower than those measured at the near-dam area of the reservoir (Figure 6.32). Secchi depths increased from upstream to downstream (Figure 6.32).

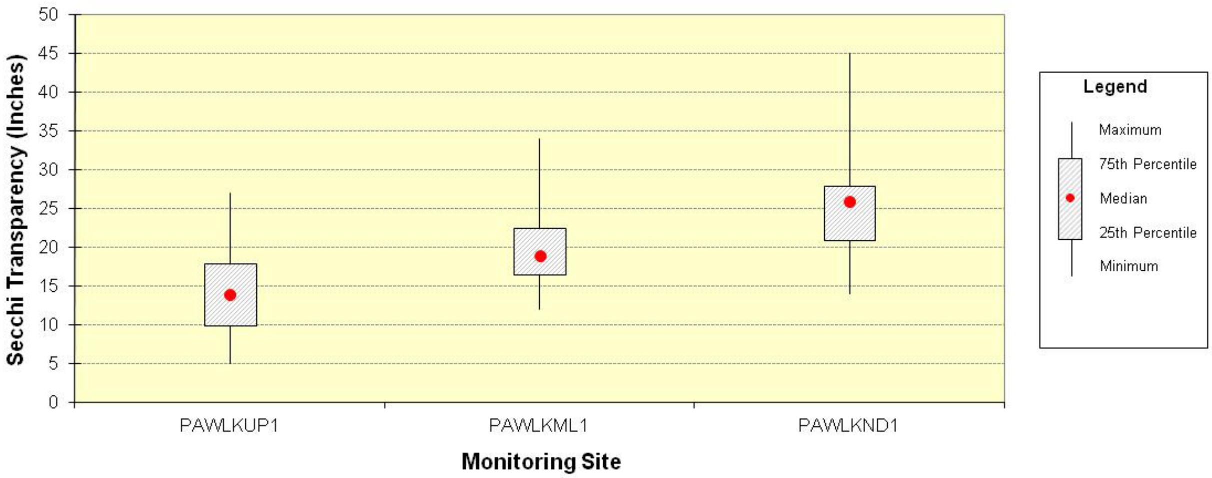

Figure 6.32. Box plot of Secchi depth transparencies measured in Pawnee Reservoir from 2008 through 2010. (Note: monitoring sites are oriented on the x-axis in an upstream to downstream direction.)**.**

6.2.7.2.1.5.2 <u>Turbidity</u>

Turbidity contour plots were constructed along the length of Pawnee Reservoir based on depth-profile measurements taken during 2009 and 2010. Plates 178 and 179, respectively, provide longitudinal turbidity contour plots based on depth-profile measurements taken from May through September. Pawnee Reservoir commonly exhibited longitudinal and depth variation in turbidity (Plates 178 and 179).

6.2.7.2.1.6 Reservoir Trophic Status

Trophic State Index (TSI) values for Pawnee Reservoir were calculated from monitoring data collected during the 5-year period 2006 through 2010 at the near-dam ambient monitoring site (i.e., PAWLKND1). Table 6.21 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Pawnee Reservoir is in a hypereutrophic condition.

Table 6.21. Summary of Trophic State Index (TSI) values calculated for Pawnee Reservoir for the 5-year period 2006 through 2010.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	25	67	67	58	75
TSI(TP)	25	64	65	52	74
TSI(Chl)	25	70	76	40	86
TSI(Avg)	25	67	69	53	78

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values.
Note: See Section 4.1.3 for discussion of TSI calculation.

6.2.7.2.1.7 Monitoring at Swimming Beaches

Two designated swimming beaches are located on Pawnee Reservoir. Bacteria (i.e., *E. coli*) and the cyanobacteria toxin microcystin were monitored at the two swimming beaches (i.e., sites PAWLKBACT1 and PAWLKBACT2) by the NDEQ during the past 5 years. Bacteria and mycrocystin were monitored from May through September over the 5-year period 2006 through 2010.

6.2.7.2.1.7.1 <u>Bacteria Monitoring</u>

Table 6.22 summarizes the results of the bacteria sampling. The "running 5-week" geometric means were calculated as running geometric means for five consecutive weekly bacteria samples through the recreational season (i.e., May through September). The "pooled" geomean was determined by pooling all the weekly bacteria samples collected during the recreational season over the 5-year period and calculating a single geomean. All nondetects were set to 1 to calculate geomeans. The sampling results were compared to the following Nebraska water quality criteria for *E. coli* bacteria:

> *E. coli* bacteria should not exceed a geometric mean of 126/100ml. For increased confidence of the criteria, the geometric mean should be based on a minimum of five samples taken within a 30-day period. Single sample maximum allowable density for designated bathing beaches is 235/100ml.

The pooled geomeans were compared to the State of Nebraska's impairment assessment criteria regarding the assessment of the Primary Contact Recreation beneficial use using *E. coli* bacteria data. Based on those criteria a Primary Contact Recreation use in Pawnee Reservoir is not impaired due to bacteria. The higher bacteria levels monitored in the reservoir are believed to be associated with runoff events.

Table 6.22. Summary of weekly (May through September) bacteria samples collected at Pawnee Reservoir (i.e., sites PAWLKBACT1 and PAWLKBACT2) during the 5-year period 2006 through 2010.

West Swimming Beach Site: PAWLKBACT1			
***E. coli* Bacteria – Individual Samples**		***E. coli* Bacteria – Geomeans**	
Number of Samples	101	Number of Geomeans	81
Mean (cfu/100ml)	65	Average	25
Median (cfu/100ml)	11	Median	15
Minimum (cfu/100ml)	1	Minimum	2
Maximum (cfu/100ml)	1,120	Maximum	118
Percent of samples exceeding 235/100ml	7%	Number of Geomeans exceeding 126/100ml	0%
		***E. coli* – Geomean (5-Year Pooled)**	
		5-Year Pooled Geomean	19
East Swimming Beach Site: PAWLKBACT2			
***E. coli* Bacteria – Individual Samples**		***E. coli* Bacteria – Geomeans**	
Number of Samples	102	Number of Geomeans	83
Mean (cfu/100ml)	305	Average	32
Median (cfu/100ml)	10	Median	11
Minimum (cfu/100ml)	1	Minimum	1
Maximum (cfu/100ml)	19,863	Maximum	354
Percent of samples exceeding 235/100ml	10%	Number of Geomeans exceeding 126/100ml	7%
		***E. coli* – Geomean (5-Year Pooled)**	
		5-Year Pooled Geomean	13

6.2.7.2.1.7.2 Microcystin Monitoring

Table 6.23 summarizes the microcystin monitoring conducted at the Pawnee Reservoir swimming beaches during the 5-year period 2006 through 2010. These results were compared to the 20 ug/l criterion for issuing health advisories and the posting of swimming beaches. Seventeen percent of the samples collected in Pawnee Reservoir exceeded the criterion for microcystin. The monitored levels of microcystin indicate a significant cyanobacteria toxin concern at Pawnee Reservoir. Based on the State of Nebraska's impairment assessment criteria, the monitored levels of microcystin may indicate impairment of the Primary Contact Recreation beneficial use of Pawnee Reservoir due to algal toxins.

Table 6.23. Summary of weekly (May through September) microcystin samples collected at Pawnee Reservoir (i.e., sites PAWLKBACT1 and PAWLKBACT2) during the 5-year period 2006 through 2010.

Summary Statistic	West Swimming Beach (Site PAWLKBACT1)	East Swimming Beach (Site PAWLKBACT2)
Number of Samples	102	104
Minimum (ug/l)	0.01	0.01
25th percentile (ug/l)	1.2	0.72
Median (ug/l)	3.2	2.9
75th Percentile (ug/l)	8.4	10.9
Maximum (ug/l)	100	100
Percent of samples exceeding 20 ug/l	18%	17%

6.2.7.2.2 Water Quality Trends (1980 through 2010)

Water quality trends from 1980 to 2010 were determined for Pawnee Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through September at the near-dam monitoring site (i.e., PAWLKND1). Plate 180 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, Pawnee Reservoir exhibited increasing trends in transparency, total phosphorus, and chlorophyll *a* levels.

Over the 29-year period since 1980, Pawnee Reservoir has remained in a slightly hypereutrophic condition (Plate 180).

6.2.7.2.3 Existing Water Quality Conditions of Runoff Inflows to Pawnee Reservoir

Existing water quality conditions in the main tributary inflow to Pawnee Reservoir was monitored at site PAWNF1 by the NDEQ under runoff conditions during the period of April through September (Figure 6.31). Site PAWNF1 was approximately 1 mile upstream from the reservoir. Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from "base-flow" conditions. Plate 181 summarizes water quality conditions that were monitored at site PAWNF1 under runoff conditions during the 5-year period 2004 through 2008. Tributary inflows to Pawnee Reservoir were not monitored in 2009 and 2010.

6.2.8 STAGECOACH RESERVOIR

6.2.8.1 Background Information

6.2.8.1.1 Project Overview

The dam forming Stagecoach Reservoir is located on a tributary of the Hickman Branch. The dam was completed on August 27, 1963 and the reservoir reached its initial fill in May 1965. The Stagecoach Reservoir watershed is 9.7 square miles. The watershed was largely agricultural when the dam was built in 1963 and has remained so to the present time.

6.2.8.1.2 Stagecoach Dam Intake Structure

The dam intake at Stagecoach Dam is a drop inlet structure consisting of a single reinforced concrete box shaft. Its inside dimensions are 4 feet by 6 feet. The intake structure has four ungated openings – two 24" x 72" openings with a crest elevation at 1277.1 ft-msl and two 12" x 30" openings with a crest elevation at 1271.1. A 36" x 36" gated opening with a crest elevation of 1261.0 ft-msl was constructed into the upstream wall. The purpose of the gated opening is to lower the level of the conservation pool in order to inspect the conduit, make shoreline repairs, and manage fish populations. It may also be used to release water for downstream needs.

6.2.8.1.3 Reservoir Storage Zones

Figure 6.33 depicts the current storage zones of Stagecoach Reservoir based on the 1990 survey data and estimated sedimentation. It is estimated that 24 to 31 percent of the "as-built" volume to the top of the Conservation Pool has been lost to sedimentation as of 2010. The annual volume loss is estimated to be 0.50 to 0.67 percent. Based on the State of Nebraska's impairment assessment methodology, these values indicate that Stagecoach Reservoir's water quality dependent uses may be impaired due to sedimentation.

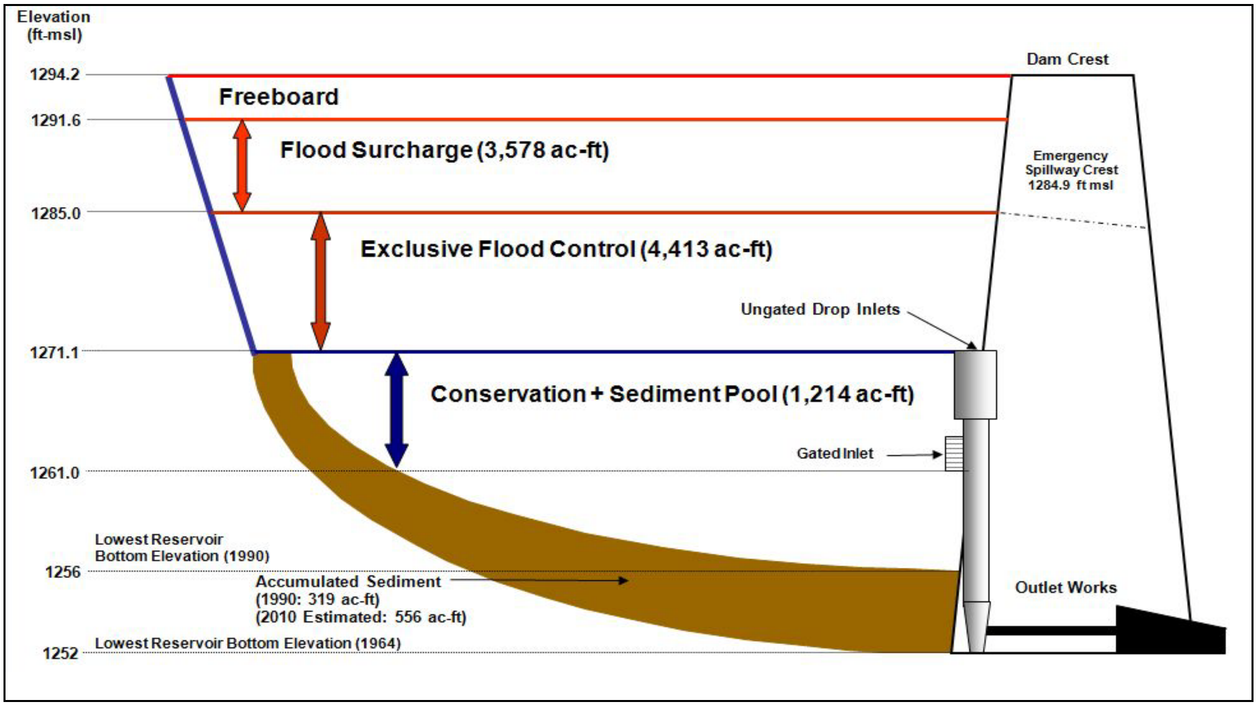

Figure 6.33. Current storage zones of Stagecoach Reservoir based on the 1990 survey data and estimated sedimentation**.**

6.2.8.1.4 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Stagecoach Reservoir since the late 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Figure 6.34 shows the location of the sites that have been monitored for water quality during the past 5 years (i.e., 2006 through 2010). The inflow runoff site (STGNF1) was sampled by the NDEQ. The other in-reservoir sites (STGLKND1, STGLKML1, and STGLKUP1) were sampled by the District. The near-dam location (STGLKND1) has been continuously monitored by the District since 1980.

6.2.8.2 <u>Water Quality in Stagecoach Reservoir</u>

6.2.8.2.1 Existing Water Quality Conditions

6.2.8.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Stagecoach Reservoir at sites STGLKND1 and STGLKML1 from May through September during the 5-year period 2006 through 2010 are summarized, respectively, in Plates 182 and 183. A review of these results indicated possible water quality concerns regarding dissolved oxygen, atrazine, and nutrients.

Figure 6.34. Location of sites where water quality monitoring was conducted at Stagecoach Reservoir during the period 2006 through 2010.

An appreciable number (>19%) of dissolved oxygen measurements throughout Stagecoach Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plates 182 and 183). Most of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and may have been associated with a slight thermal stratification. Nebraska's Water Quality Standards makes the following provision regarding the application of the State's water quality standards' criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision possibly applies to the low dissolved oxygen situation in Stagecoach Reservoir, and the measured dissolved oxygen levels below 5 mg/l may not be a water quality standards non-attainment situation. However, dissolved oxygen measurements on August 16, 2010 were below the5 mg/l criterion for the protection of warmwater aquatic life from the reservoirs surface to bottom.

The chronic atrazine criterion for the protection of warmwater aquatic life was exceeded in 1 of 25 samples collected from Stagecoach Reservoir in the area near the dam (Plate 182). It is not considered a significant water quality concern at this time.

Nutrient criteria defined in Nebraska's water quality standards for R13 impounded waters include: total phosphorus (50 ug/l), total nitrogen (1,000 ug/l), and chlorophyll *a* (10 ug/l). All three of these criteria were exceeded throughout Stagecoach Reservoir (Plates 182 and 183). The total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 98, 100, and 46 percent of the samples collected at site STGLKND1. All the samples were collected during the "growing season" (i.e., May through September) and the reported mean values represent the growing season average for the 5-year period 2006 through 2010. Based on the State of Nebraska's impairment assessment criteria, the mean values for the three parameters (Plate 182) indicate impairment of the Aquatic Life beneficial use of Stagecoach Reservoir due to nutrients.

6.2.8.2.1.2 Thermal Stratification

6.2.8.2.1.2.1 Longitudinal Temperature Contour Plots

Late-spring and summer thermal conditions of Stagecoach Reservoir measured during 2009 and 2010 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plates 184 and 185, respectively, provide longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites STGLKND1, STGLKML1, and STGLKUP1 in 2009 and 2010. These temperature plots indicate that Stagecoach Reservoir rarely exhibited significant thermal stratification during the 2-year period. The maximum difference monitored between the surface and bottom water temperatures during the 2-year period was 3°C in June of 2009 (Plate 184).

6.2.8.2.1.2.2 Near-Dam Temperature Depth-Profile Plots

Existing summer thermal stratification of Stagecoach Reservoir, at the deep water area near the dam, measured over the 5-year period 2006 through 2010 is depicted by depth-profile temperature plots (Plate 186). The depth-profile temperature plots indicate that the reservoir rarely exhibited significant summer thermal stratification over the past 5 years. Since Stagecoach Reservoir ices over in the winter and seemingly exhibits periodic circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.2.8.2.1.3 Summer Dissolved Oxygen Conditions

6.2.8.2.1.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Stagecoach Reservoir based on depth-profile measurements taken during 2009 and 2010 at sites STGLKND1, STGLKML1, and STGLKUP1. Plates 187 and 188, respectively, provide longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September in 2009 and 2010. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored on one occasion (September of 2009) in a small area near the reservoir bottom (Plates 187 and 188).

6.2.8.2.1.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

Existing summer dissolved oxygen conditions in Stagecoach Reservoir are described by the dissolved oxygen depth-profiles measured near the dam over the 5-year period 2006 through 2010. Summer depth-profile dissolved oxygen plots were compiled for the 5 years (Plate 189). On several occasions there was a significant vertical gradient in summer dissolved oxygen levels. Although Stagecoach Reservoir appears to be polymictic based on thermal stratification, there appears to be enough inhibition to mixing to allow hypoxic conditions to occasionally develop near the reservoir bottom.

6.2.8.2.1.3.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of Stagecoach Reservoir with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2009 and 2010 and the District's current Area-Capacity Tables (1990 Survey) for the reservoir. The constructed contour plots were reviewed to identify the "worst-case" dissolved oxygen condition. The "worst-case" condition was taken to be the contour plot with the highest elevations of the 5 mg/l and 2.5 mg/l dissolved oxygen isopleths. The September 11, 2009 contour plot indicates a pool elevation of 1270.7 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1263.0 ft msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1261.0 ft-msl (Plate 187). The District's Area-Capacity Tables give storage capacities of 1,374 ac-ft for elevation 1270.7 ft-msl, 304 ac-ft for elevation 1263.0 ft-msl, and 156 ac-ft for elevation 1261.0 ft-msl. On September 11, 2009 it is estimated that 22 percent of the volume of Stagecoach Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 11 percent of the reservoir volume was hypoxic.

The August 16, 2010 contour plot indicates a pool elevation of 1271.0 ft-msl and a 5 mg/l dissolved oxygen isopleth elevation greater than 1271.0 ft msl (Plate 188). Nearly 15 percent of the reservoir is below the 5 mg/l criterion for the protection of warmwater aquatic life from surface to bottom.

6.2.8.2.1.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in Stagecoach Reservoir indicated limited hypoxic conditions were present during the summers of 2009 and 2010, only depth-profile plots were constructed for ORP and pH. Construction of longitudinal contour plots for ORP and pH and comparison of near-surface and near-bottom water quality samples were not done.

6.2.8.2.1.4.1 Oxidation-Reduction Potential

Plate 190 plots depth profiles for ORP measured during the summer over the 5-year period of 2006 through 2010 in the deep water area of Stagecoach Reservoir near the dam. The depth profiles indicate very little depth variability in ORP levels during the summer over the 5-year period (Plate 190).

6.2.8.2.1.4.2 pH

Plate 191 plots depth profiles for pH measured during the summer over the 5-year period of 2006 through 2010 in the deep water area of Stagecoach Reservoir near the dam. The depth profiles indicate that pH levels, on some occasions, varied by up to 1.0 S.U. from the surface to the bottom of Stagecoach Reservoir (Plate 191).

6.2.8.2.1.5 Water Clarity

6.2.8.2.1.5.1 Secchi Transparency

Figure 6.35 displays a box plot of the Secchi depth transparencies measured at the three in-reservoir monitoring sites (i.e., STGLKND1, STGLKML1, and STGLKUP1) from 2008 through 2010 (note: the monitoring sites are oriented in an upstream to downstream direction). The Secchi depth transparencies measured at the three sites were similar (Figure 6.35).

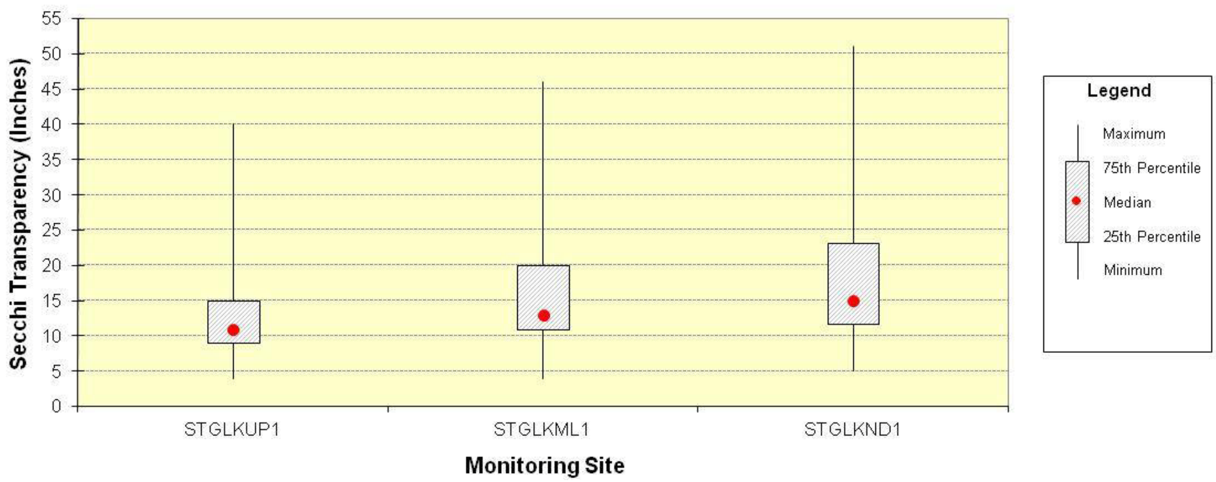

Figure 6.35. Box plot of Secchi depth transparencies measured in Stagecoach Reservoir from 2008 through 2010. (Note: monitoring sites are oriented on the x-axis in an upstream to downstream direction.)**.**

6.2.8.2.1.5.2 Turbidity

Turbidity contour plots were constructed along the length of Stagecoach Reservoir based on depth-profile measurements taken during 2009 and 2010. Plates 192 and 193, respectively, provide longitudinal turbidity contour plots based on depth-profile measurements taken from May through September. Stagecoach Reservoir commonly exhibited significant longitudinal and depth variability in turbidity (Plates 192 and 193).

6.2.8.2.1.6 Reservoir Trophic Status

Trophic State Index (TSI) values for Stagecoach Reservoir were calculated from monitoring data collected during the 5-year period 2006 through 2010 at the near-dam ambient monitoring site (i.e., STGLKND1). Table 6.24 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Stagecoach Reservoir is in a hypereutrophic condition.

Table 6.24. Summary of Trophic State Index (TSI) values calculated for Stagecoach Reservoir for the 5-year period 2006 through 2010.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	24	71	74	3	90
TSI(TP)	25	66	66	55	78
TSI(Chl)	24	63	62	40	83
TSI(Avg)	25	66	68	41	79

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values.

Note: See Section 4.1.3 for discussion of TSI calculation.

6.2.8.2.2 Water Quality Trends (1980 through 2010)

Water quality trends from 1980 to 2010 were determined for Stagecoach Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through October at the near-dam monitoring site (i.e., STGLKND1). Plate 194 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, Stagecoach Reservoir exhibited slightly decreasing trends in transparency and chlorophyll *a*, and an increasing trend in total phosphorus levels (Plate 194). Over the 29-year period since 1980, Stagecoach Reservoir has remained in a hypereutrophic condition (Plate 194).

6.2.8.2.3 Existing Water Quality Conditions of Runoff Inflows to Stagecoach Reservoir

Existing water quality conditions in the south tributary inflow to Stagecoach Reservoir was monitored at site STGNF1 by the NDEQ under runoff conditions during the period of April through September (Figure 6.34). Site STGNF1 was approximately 1 mile upstream from the reservoir. Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from "base-flow" conditions. Plate 189 summarizes water quality conditions that were monitored at site STGNFSTH1 under runoff conditions during the 5-year period 2004 through 2008. Tributary inflows to Stagecoach Reservoir were not monitored in 2009 and 2010.

6.2.9 TWIN LAKES RESERVOIR (EAST AND WEST TWIN RESERVOIRS)

6.2.9.1 Background Information

6.2.9.1.1 Project Overview

The dam forming Twin Lakes Reservoir is located on Middle Creek. The dam was completed on September 26, 1965 and the reservoir reached its initial fill on March 18, 1969. Twin Lakes Reservoir is composed of and east and west arm. The two arms of the reservoir basins are connected by a channel. The purpose of the connecting channel is to interconnect the reservoirs of the two embankments so they operate as a single reservoir with one outlet works and one spillway at the east embankment. Under

lower pool levels, the two arms are referred to separately as the East and West Twin Reservoirs (see Figure 6.37). The Twin Lakes Reservoir watershed is 11.0 square miles. The watershed was largely agricultural when the dam was built in 1965 and has remained so to the present time.

6.2.9.1.2 Twin Lakes Dam Intake Structure

The dam intake at East Twin Reservoir is a drop inlet structure consisting of a single reinforced concrete box shaft. Its inside dimensions are 42 inches by 63 inches. The intake structure has two 24" x 63" ungated openings with a crest elevation at 1341.0 ft-msl. A 42" x 54" gated opening with a crest elevation of 1333.0 ft-msl was constructed into the upstream wall. The purpose of the gated opening is to lower the level of the conservation pool in order to inspect the conduit, make shoreline repairs, and manage fish populations. It may also be used to release water for downstream needs.

6.2.9.1.3 Reservoir Storage Zones

Figure 6.36 depicts the current storage zones of Twin Lakes Reservoir based on the 1994 survey data and estimated sedimentation. It is estimated that 24 to 36 percent of the "as-built" volume to the top of the Conservation Pool has been lost to sedimentation as of 2010. The annual volume loss is estimated to be 0.54 to 0.80 percent. Based on the State of Nebraska's impairment assessment methodology, these values indicate that Twin Lakes Reservoir's water quality dependent uses are possibly impaired due to sedimentation.

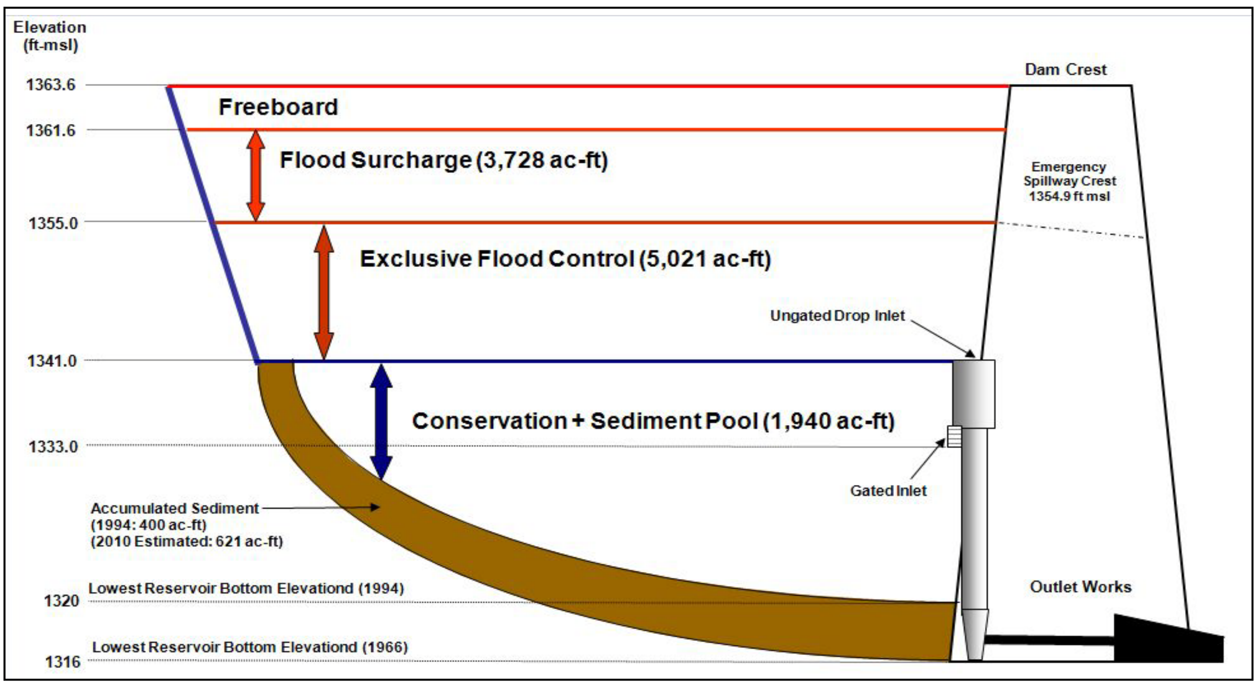

Figure 6.36. Current storage zones of Twin Lakes Reservoir based on the 1994 survey data and estimated sedimentation**.**

6.2.9.1.4 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Twin Lakes Reservoir since the late 1970's. Water quality monitoring locations have included sites on both reservoirs and on the inflow and outflow of the reservoir. Figure 6.37 shows the location of the sites that have been monitored for water

quality during the past 5 years (i.e., 2006 through 2010). The inflow runoff sites (ETNNF1 and WTNNF1) were sampled by the NDEQ. The other in-reservoir sites (ETNLKND1, ETNNF1, ETNLKUP1, and WTNLKND1) were sampled by the District. The near-dam locations (ETNLKD1 and WTNLKND1) have been monitored since 1980; however, site WTNLKND1 was not monitored during the period 2006 through 2010 due to low water conditions.

6.2.9.2 <u>Water Quality in East Twin Reservoir</u>

6.2.9.2.1 Existing Water Quality Conditions

6.2.9.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in East Twin Reservoir at sites ETNLKND1 and ETNLKML1 from May through September during the 5-year period 2006 through 2010 are summarized, respectively, in Plates 196 and 197. A review of these results indicated possible water quality concerns regarding dissolved oxygen, selenium, and nutrients.

An appreciable number (>14%) of dissolved oxygen measurements taken in East Twin Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plate 196 and 197). Most of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and may have been associated with a slight thermal stratification. Nebraska's Water Quality Standards makes the following provision regarding the application of the State's water quality standards' criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen situation in East Twin Reservoir, and the measured dissolved oxygen levels below 5 mg/l may not be a water quality standards non-attainment situation.

One of five selenium measurements (20%) exceeded the chronic criterion for the protection of aquatic life. At this time the exceedence is considered to be a possible outlier.

Nutrient criteria defined in Nebraska's water quality standards for R13 impounded waters include: total phosphorus (50 ug/l), total nitrogen (1,000 ug/l), and chlorophyll *a* (10 ug/l). All three of these criteria were exceeded throughout East Twin Reservoir (Plate 196 and 197). The total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 90, 100, and 80 percent of the samples collected at site ETNLKND1. All the samples were collected during the "growing season" (i.e., May through September) and the reported mean values represent the growing season average for the 5-year period 2006 through 2010. Based on the State of Nebraska's impairment assessment criteria, the mean values for total nitrogen and chlorophyll *a* (Plate 196) indicate impairment of the Aquatic Life beneficial use of East Twin Reservoir due to nutrients.

Figure 6.37. Location of sites where water quality monitoring was conducted at Twin Lakes Reservoir during the period 2006 through 2010.

6.2.9.2.1.2 Thermal Stratification

6.2.9.2.1.2.1 Longitudinal Temperature Contour Plots

Late-spring and summer thermal conditions of East Twin Reservoir measured during 2009 and 2010 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plates 198 and 199, respectively, provide longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites ETNLKND1, ETNLKML1, and ETNLKUP1 in 2009 and 2010. These temperature plots indicate that East Twin Reservoir rarely exhibited significant thermal stratification during the 2-year period. The maximum difference monitored between the surface and bottom water temperatures during the 2-year period was 5°C in July of 2009 (Plate 198).

6.2.9.2.1.2.2 Near-Dam Temperature Depth-Profile Plots

Existing summer thermal stratification of East Twin Reservoir, at the deep water area near the dam, measured over the 5-year period 2006 through 2010 is depicted by depth-profile temperature plots (Plate 200). The depth-profile temperature plots indicate that the reservoir rarely exhibited significant summer thermal stratification over the past 5 years. Since East Twin Reservoir ices over in the winter and seemingly exhibits periodic circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.2.9.2.1.3 Summer Dissolved Oxygen Conditions

6.2.9.2.1.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of East Twin Reservoir based on depth-profile measurements taken during 2009 and 2010 at sites ETNLKND1, ETNLKML1, and ETNLKUP1. Plates 201 and 202, respectively, provide longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September in 2009 and 2010. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored on five occasions (in June, July, and September 2009, in July and August 2010) near the reservoir bottom (Plates 201 and 202).

6.2.9.2.1.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

Existing summer dissolved oxygen conditions in East Twin Reservoir are described by the dissolved oxygen depth-profiles measured near the dam over the 5-year period 2006 through 2010. Summer depth-profile dissolved oxygen were compiled and plotted for the 5 years (Plate 203). On several occasions there was a significant vertical gradient in summer dissolved oxygen levels. Both hypoxic conditions near the bottom and super-saturation near the reservoir surface were monitored (Plate 203). Although East Twin Reservoir appears to be polymictic based on thermal stratification, there appears to be enough inhibition to mixing to allow hypoxic conditions to develop near the reservoir bottom.

6.2.9.2.1.3.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of East Twin Reservoir with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2009 and 2010 and the District's current Area-Capacity Tables (1994 Survey) for the reservoir. The constructed contour plots were reviewed to identify the "worst-case" dissolved oxygen condition. The "worst-case" condition was taken to be the contour plot with the highest elevations of the 5 mg/l and 2.5 mg/l dissolved oxygen isopleths. The

August 11, 2010 contour plot indicates a pool elevation of 1340.9 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1332.5 ft msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1331.5ft-msl (Plate 202). The District's Area-Capacity Tables give storage capacities of 2,138 ac-ft for elevation 1340.9 ft-msl, 718 ac-ft for elevation 1332.5 ft-msl, and 608 ac-ft for elevation 1331.5 ft-msl. On August 11, 2010 it is estimated that 34 percent of the volume of East Twin Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 28 percent of the reservoir volume was hypoxic.

6.2.9.2.1.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in East Twin Reservoir indicated hypoxic conditions were present during the summers of 2009 and 2010, longitudinal contour and depth-profile plots were constructed for ORP and pH. Near-surface and near-bottom water quality samples collected when hypoxia was present were also compared.

6.2.9.2.1.4.1 Oxidation-Reduction Potential

Plates 204 and 205, respectively, provide longitudinal ORP contour plots based on depth-profile measurements taken in 2009 and 2010. The ORP values indicated reduced conditions occurred near the reservoir bottom on two occasions when hypoxic conditions were monitored (July 7, 2009 and August 11, 2010) (Plates 204 and 205). Plate 206 plots depth profiles for ORP measured during the summer over the past 5 years in the deep water area of East Twin Reservoir near the dam. The ORP depth profiles indicate that appreciable reduced conditions rarely occurred in East Twin Reservoir during the summer (Plate 206).

6.2.9.2.1.4.2 pH

Longitudinal contour plots for pH conditions measured in 2009 and 2010 are provided, respectively, in Plates 207 and 208. Plate 209 plots depth profiles for pH measured during the summer over the past 5 years in the deep water area of East Twin Reservoir near the dam. An appreciable vertical gradient in pH occasionally occurred in the reservoir during the summer (Plates 207-209). The highest pH values occurred on August 11, 2011, when 48 percent of East Twin Reservoir was above the upper pH criterion of 9.0 for the protection of warmwater aquatic life. The high pH values are likely associated with periods of high algal production and CO_2 uptake during photosynthesis.It appears occasional reduced conditions in the deeper water of Wagon Train Reservoir seemingly lead to in lower pH levels near the reservoir bottom. The lowest measured pH levels near the reservoir bottom were above the lower pH criterion of 6.5 for the protection of warmwater aquatic life.

6.2.9.2.1.4.3 Comparison of Near-Surface and Near-Bottom Water Quality Conditions

Paired near-surface and near-bottom water quality samples collected from East Twin Reservoir during the summer when hypoxia was present were compared. Near-surface conditions were represented by samples collected within 1-meter of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site ETNLKND1 during the 5-year period 2006 through 2010. During the 5-year period a total of 25 paired samples were collected monthly from May through September. Of the 25 paired samples collected, 12 (48%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature ,dissolved oxygen, oxidation-reduction potential, pH, alkalinity, total ammonia, nitrate-nitrate nitrogen, total phosphorus, and orthophosphorus (Plate 210) *[Note: there were 12 paired observations for each*

parameter]. A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were not significantly different for nitrate-nitrite nitrogen, total phosphorus, or ortho-phosphorus. Parameters that were significantly lower in the near-bottom water of East Twin Reservoir when hypoxia was present included: water temperature ($p < 0.0001$), dissolved oxygen ($p < 0.0001$), oxidation-reduction potential (< 0.001), and pH ($p < 0.0001$). Parameters that were significantly higher in the near-bottom water of East Twin Reservoir when hypoxia was present included: total ammonia ($p < 0.05$), total alkalinity ($p < 0.05$).

6.2.9.2.1.5 Water Clarity

6.2.9.2.1.5.1 <u>Secchi Transparency</u>

Figure 6.38 displays a box plot of the Secchi depth transparencies measured at the three in-reservoir monitoring sites (i.e., ETNLKND1, ETNLKML1, and ETNLKUP1) from 2008 through 2010 (note: the monitoring sites are oriented in an upstream to downstream direction). The transparencies measured at all three sites were not significantly different (Figure 6.38).

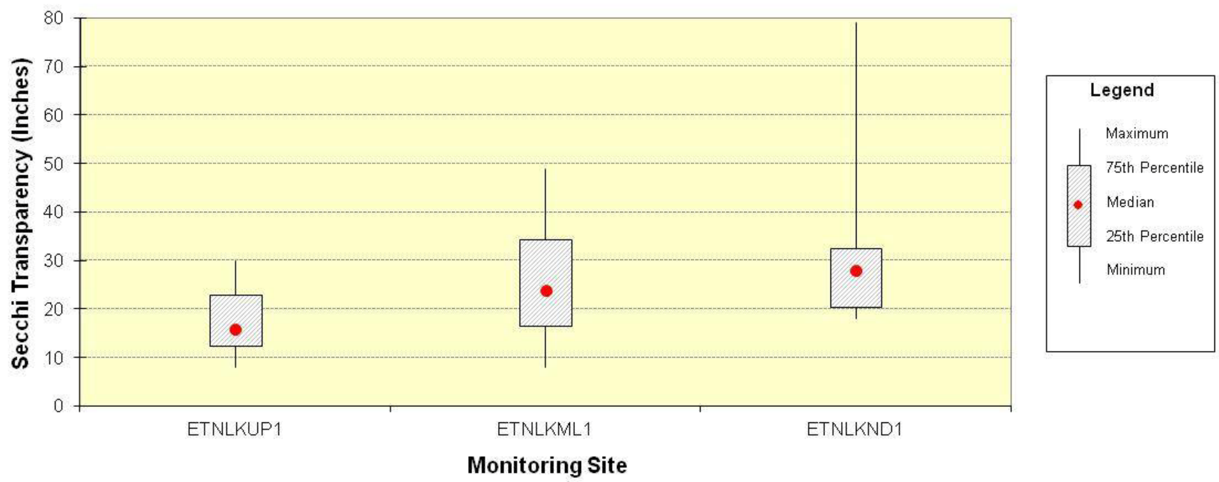

Figure 6.38. Box plot of Secchi depth transparencies measured in East Twin Reservoir from 2008 through 2010. (Note: monitoring sites are oriented on the x-axis in an upstream to downstream direction.)**.**

6.2.9.2.1.5.2 <u>Turbidity</u>

Turbidity contour plots were constructed along the length of East Twin Reservoir based on depth-profile measurements taken during 2009 and 2010. Plates 211 and 212, respectively, provide longitudinal turbidity contour plots based on depth-profile measurements taken from May through September. East Twin Reservoir occasionally exhibited appreciable longitudinal and depth variability in turbidity.

6.2.9.2.1.6 Reservoir Trophic Status

Trophic State Index (TSI) values for East Twin Reservoir were calculated from monitoring data collected during the 5-year period 2006 through 2010 at the near-dam ambient monitoring site (i.e., ETNLKND1). Table 6.25 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of East Twin Reservoir is in a slightly hypereutrophic condition.

Table 6.25. Summary of Trophic State Index (TSI) values calculated for East Twin Reservoir for the 5-year period 2006 through 2010.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	25	66	66	50	80
TSI(TP)	25	63	61	52	77
TSI(Chl)	25	69	72	40	83
TSI(Avg)	25	66	67	52	71

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values.

Note: See Section 4.1.3 for discussion of TSI calculation.

6.2.9.2.2 Water Quality Trends (1980 through 2010)

Water quality trends from 1980 to 2010 were determined for East Twin Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through September at the near-dam monitoring site (i.e., ETNLKND1). Plate 213 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, East Twin Reservoir exhibited slight increases in transparency and chlorophyll *a*, and a slight decrease in total phosphorus. Over the 31-year period since 1980, East Twin Reservoir has remained in a slightly hypereutrophic condition (Plate 213).

6.2.9.2.3 Existing Water Quality Conditions of Runoff Inflows to East Twin Reservoir

Existing water quality conditions in the main tributary inflow to East Twin Reservoir was monitored at site ETNNF1 by the NDEQ under runoff conditions during the period of April through September (Figure 6.37). Site ETNNF1 was approximately ¼ mile upstream from the reservoir. Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from "base-flow" conditions. Plate 208 summarizes water quality conditions that were monitored at site ETNNF1 under runoff conditions during the period 2004 through 2008. Tributary inflows to East Twin Reservoir were not monitored in 2009 and 2010.

6.2.10 WAGON TRAIN RESERVOIR

6.2.10.1 Background Information

6.2.10.1.1 Project Overview

The dam forming Wagon Train Reservoir is located on a tributary to the Hickman Branch. The dam was completed on September 24, 1962 and the reservoir reached its initial fill on June 24, 1963. The Wagon Train Reservoir watershed is 15.6 square miles. The watershed was largely agricultural when the dam was built in 1962 and has remained so to the present time.

6.2.10.1.2 Aquatic Habitat Improvement and Water Quality Management Project

A lake renovation project was completed at Wagon Train Reservoir in 2003. The goal of the project was to stabilize eroding shorelines and create fringe wetlands, reduce sediment and nutrient loading to the reservoir, manipulate water levels to promote colonization of aquatic vegetation, eliminate

the rough fish dominated community using rotenone, and restock the reservoir with sport fish. Approximately $2.7 million in Federal, State, and Local funding was spent on the lake renovation project.

Included in the project were the construction of a two-stage sediment/nutrient dike in the upper end of the reservoir and a single-stage sediment/nutrient dike at the upper end of the east bay (Figure 6.39). Each dike has an estimated trapping efficiency of about 60 percent. Further, five breakwater jetties totaling 1,175 feet were constructed at strategic locations and now protect 2,350 additional feet of adjacent shoreline from erosive waves. Finally, three islands were constructed just downstream of the large sediment/nutrient dike and have each added about 1,000 feet of shoreline. Collectively, the structures created in this project have added 8,750 feet of additional shoreline, increasing the reservoir's total by 36 percent. The dikes, jetties, and islands have all promoted growth of cattails, bulrushes, arrowhead, and a variety of submersed aquatic plants. This aquatic vegetation is resulting in development of an exceptional fishery. To protect this fishery from unwanted reintroduction of rough fish, the Nebraska Game and Parks Commission has implemented a ban on the possession and use of all baitfish, dead or alive, at the reservoir.


Two-Stage Sediment/Nutrient Dike and Basin


One-Stage Sediment/Nutrient Dike and Basin.

Figure 6.39. Aerial views of sediment/nutrient dikes and basins constructed on Wagon Train Reservoir as part of the lake renovation project (see Figure 6.41 for constructed sediment/nutrient dikes locations on the reservoir).

6.2.10.1.3 Wagon Train Dam Intake Structure

The dam intake at Wagon Train Dam is a drop inlet structure consisting of a single reinforced concrete box shaft. Its inside dimensions are 5 feet by 8 feet. The intake structure has four ungated openings – two 30" x 96" openings with a crest elevation at 1292.4 ft-msl and two 12" x 54" openings with a crest elevation at 1287.8. A 36" x 36" gated opening with a crest elevation of 1283.5 ft-msl was constructed into the upstream wall. As part of the recent lake renovation project a "stop-log" structure was attached to the concrete box shaft over the 36" x 36" gated opening. The 36" x 36" gate is permanently left open and pool levels are managed with the external stop-log structure. The purpose of the gate modification is to allow for better management of pool elevations for water quality and fishery management. The gated outlet may also be used to release water for downstream needs.

6.2.10.1.4 Reservoir Storage Zones

Figure 6.40 depicts the current storage zones of Wagon Train Reservoir based on the 1993 survey data, results of the recent lake renovation project, and estimated sedimentation. After accounting for the sediment removed from the reservoir basin as part of the recent lake renovation project, it is estimated

that 13 percent of the “as-built” volume to the top of the Conservation Pool has been lost to sedimentation as of 2010. The annual volume loss, prior to the implementation of the lake renovation project, is estimated to be 0.31 percent. However, measures implemented as part of the lake renovation project (i.e., sediment/nutrient dikes) are believed to have reduced the annual volume loss. Based on the State of Nebraska’s impairment assessment criteria, these values indicate that Wagon Train Reservoir’s water quality dependent uses are not impaired due to sedimentation.

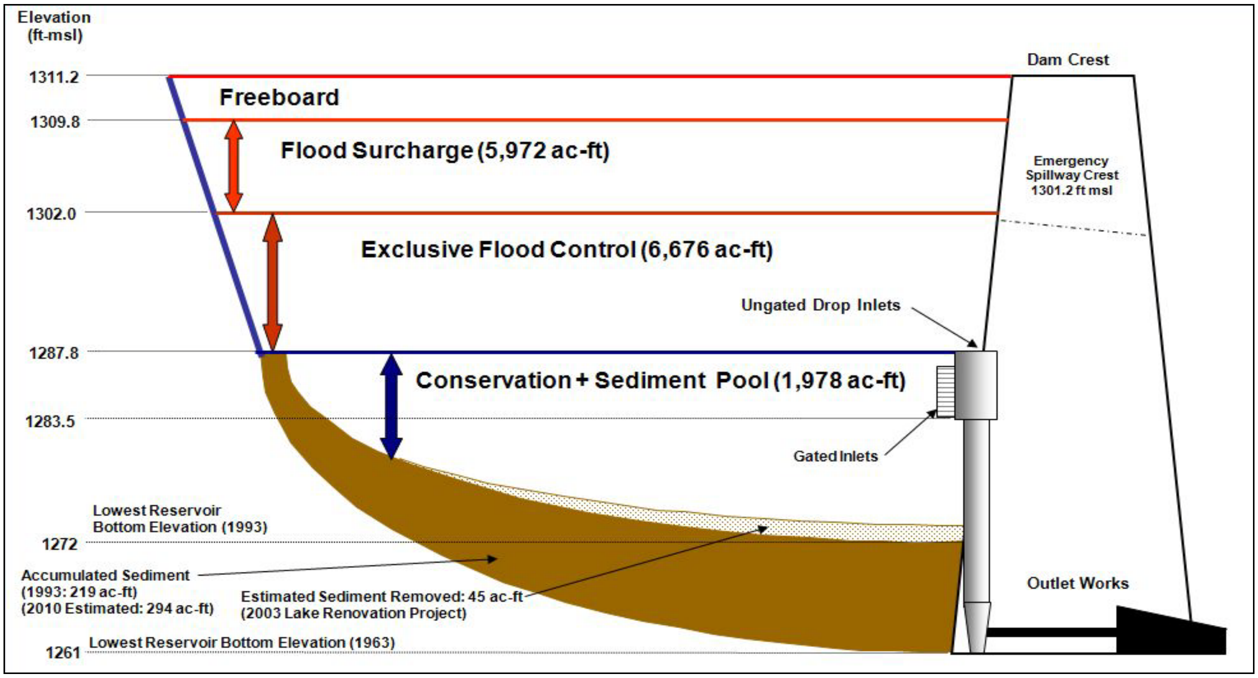

Figure 6.40. Current storage zones of Wagon Train Reservoir based on the 1993 survey data and estimated sedimentation**.**

6.2.10.1.5 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Wagon Train Reservoir since the late 1970’s. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Figure 6.41 shows the location of the sites that have been monitored for water quality during the past 5 years (i.e., 2006 through 2010). The inflow runoff site (WAGNF1) was sampled by the NDEQ. The other in-reservoir sites (WAGLKND1, WAGLKML1, and WAGLKUP1) were sampled by the District. The near-dam location (WAGLKND1) has been monitored by the District since 1980.

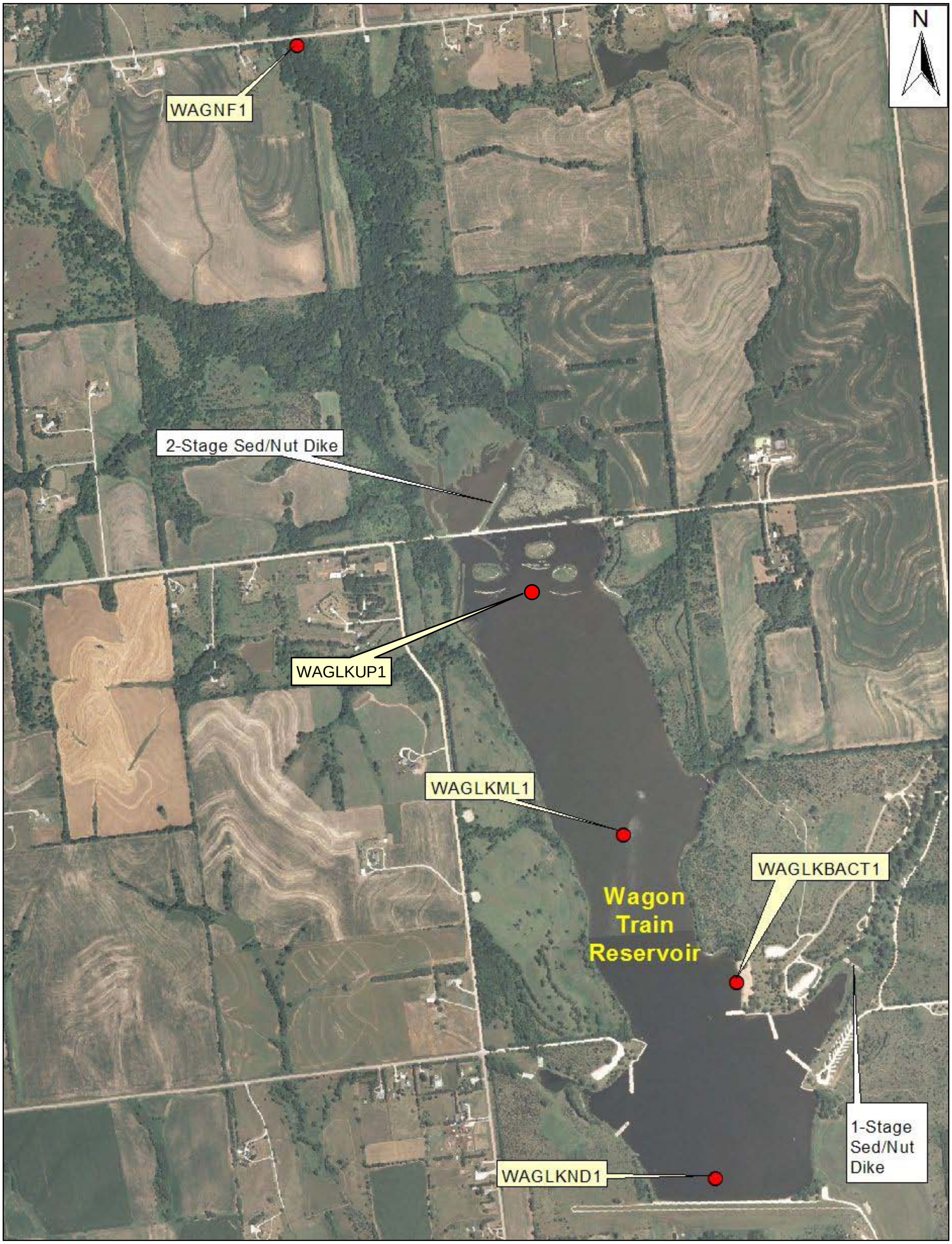

Figure 6.41. Location of sites where water quality monitoring was conducted at Wagon Reservoir during the period 2006 through 2010

6.2.10.1 <u>Water Quality in Wagon Train Reservoir</u>

6.2.10.1.1 Existing Water Quality Conditions

6.2.10.1.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Wagon Train Reservoir at sites WAGLKND1 and WAGLKML1 from May through September during the 5-year period 2006 through 2010 are summarized, respectively, in Plates 215 and 216. A review of these results indicated possible water quality concerns regarding dissolved oxygen, arsenic, aluminum, and selenium.

An appreciable number (>28%) of dissolved oxygen measurements taken in Wagon Train Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plate 215 and 216). Most of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and may have been associated with a slight thermal stratification. Nebraska's Water Quality Standards makes the following provision regarding the application of the State's water quality standards' criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision possibly applies to the low dissolved oxygen situation in Wagon Train Reservoir, and the measured dissolved oxygen levels below 5 mg/l may not be a water quality standards non-attainment situation.

One of five aluminum measurements (20%) and one of five selenium measurements (20%) exceeded the chronic aluminum and selenium criteria for the protection of aquatic life. At this time the exceedences are considered to be possible outliers.

The chronic arsenic criterion for the protection of warmwater aquatic life was exceeded in 1 of the 5 samples (20%) collected from Wagon Train Reservoir in the area near the dam (Plate 215). This exceedence of the chronic arsenic criterion does not represent a standards non-attainment situation. However, concern is warranted due to previous exceedences prior to 2006.

Nutrient criteria defined in Nebraska's water quality standards for R13 impounded waters include: total phosphorus (50 ug/l), total nitrogen (1,000 ug/l), and chlorophyll *a* (10 ug/l). All three of these criteria were exceeded throughout Wagon Train Reservoir (Plates 215 and 216). The total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 100, 94, and 76 percent of the samples collected at site WAGLKND1. All the samples were collected during the "growing season" (i.e., May through September) and the reported mean values represent the growing season average for the 5-year period 2006 through 2010. Based on the State of Nebraska's impairment assessment criteria, the mean values for all three parameters (Plate 215) indicate impairment of the Aquatic Life beneficial use of Wagon Train Reservoir due to nutrients.

6.2.10.1.1.2 Thermal Stratification

6.2.10.1.1.2.1 <u>Longitudinal Temperature Contour Plots</u>

Late-spring and summer thermal conditions of Wagon Train Reservoir measured during 2007 and 2008 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plates 217 and 218, respectively, provide longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites WAGLKND1, WAGLKML1, and WAGLKUP1 in 2009 and 2010. These temperature plots indicate that Wagon Train Reservoir rarely

exhibited significant thermal stratification during the 2-year period. The maximum difference monitored between the surface and bottom water temperatures during the 2-year period was 3°C (May 2009, June 2009, and August 2010) (Plates 217 and 218).

6.2.10.1.1.2.2 Near-Dam Temperature Depth-Profile Plots

Existing summer thermal stratification of Wagon Train Reservoir, at the deep water area near the dam, measured over the 5-year period 2006 through 2010 is depicted by depth-profile temperature plots (Plate 219). The depth-profile temperature plots indicate that the reservoir rarely exhibited significant summer thermal stratification over the past 5 years. Since Wagon Train Reservoir ices over in the winter and seemingly exhibits periodic circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.2.10.1.1.3 Summer Dissolved Oxygen Conditions

6.2.10.1.1.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Wagon Train Reservoir based on depth-profile measurements taken during 2009 and 2010 at sites WAGLKND1, WAGLKML1, and WAGLKUP1. Plates 220 and 221, respectively, provide longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September in 2009 and 2010. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored on five occasions (July and August 2009 and 2010, and September 2009) near the reservoir bottom (Plates 220 and 221).

6.2.10.1.1.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

Existing summer dissolved oxygen conditions in Wagon Train Reservoir are described by the dissolved oxygen depth-profiles measured near the dam over the 5-year period 2006 through 2010. Summer dissolved oxygen depth-profiles were compiled and plotted for the 5 years (Plate 222). On several occasions there was a significant vertical gradient in summer dissolved oxygen levels. Both hypoxic conditions near the reservoir bottom and super-saturation near the surface were monitored (Plate 222). Although Wagon Train Reservoir appears to be polymictic based on thermal stratification, there appears to be enough inhibition to mixing to allow hypoxic conditions to develop near the reservoir bottom.

6.2.10.1.1.3.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of Wagon Train Reservoir with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2009 and 2010 and the District's current Area-Capacity Tables (1993 Survey) for the reservoir. The constructed contour plots were reviewed to identify the "worst-case" dissolved oxygen condition. The "worst-case" condition was taken to be the contour plot with the highest elevations of the 5 mg/l and 2.5 mg/l dissolved oxygen isopleths. The August 13, 2010 contour plot indicates a pool elevation of 1288.2 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1285.3 ft msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1278.5 ft-msl (Plate 220). The District's Area-Capacity Tables give storage capacities of 1,888 ac-ft for elevation 1288.2 ft-msl, 1,204 ac-ft for elevation 1285.3 ft-msl, and 233 ac-ft for elevation 1278.5 ft-msl. On August 13, 2010 it is estimated that 64 percent of the volume of Wagon Train Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 12 percent of the reservoir volume was hypoxic.

6.2.10.1.1.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in Wagon Train Reservoir indicated hypoxic conditions were present during the summers of 2009 and 2010, longitudinal contour and depth-profile plots were constructed for ORP and pH. Near-surface and near-bottom water quality samples collected when hypoxia was present were also compared.

6.2.10.1.1.4.1 Oxidation-Reduction Potential

Plates 223 and 224, respectively, provide longitudinal ORP contour plots based on depth-profile measurements taken in 2009 and 2010. The ORP values indicated "slightly" reduced conditions occurred near the reservoir bottom on four occasions when hypoxic conditions were monitored (July and August 2009 and 2010) (Plate 224). Plate 225 plots depth profiles for ORP measured during the summer over the past 5 years in the deep water area of Wagon Train Reservoir near the dam. The ORP depth profiles indicate that appreciable reduced conditions rarely occurred in Wagon Train Reservoir during the summer (Plate 225).

6.2.10.1.1.4.2 pH

Longitudinal contour plots for pH conditions measured in 2009 and 2010 are provided, respectively, in Plates 226 and 227. Plate 228 plots depth profiles for pH measured during the summer over the past 5 years in the deep water area of Wagon Train Reservoir near the dam. An appreciable vertical gradient in pH occasionally occurred in the reservoir during the summer (Plates 226 - 228). It appears occasional reduced conditions in the deeper water of Wagon Train Reservoir seemingly lead to in lower pH levels near the reservoir bottom. The lowest measured pH levels near the reservoir bottom were above the lower pH criterion of 6.5 for the protection of warmwater aquatic life.

6.2.10.1.1.4.3 Comparison of Near-Surface and Near-Bottom Water Quality Conditions

Paired near-surface and near-bottom water quality samples collected from Wagon Train Reservoir during the summer when hypoxia was present were compared. Near-surface conditions were represented by samples collected within 1-meter of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site WAGLKND1 during the 5-year period 2006 through 2010. During the 5-year period a total of 25 paired samples were collected monthly from May through September. Of the 25 paired samples collected, nine (36%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature, dissolved oxygen, oxidation-reduction potential, pH, alkalinity, total ammonia, nitrate-nitrate nitrogen, total phosphorus, and orthophosphorus (Plate 229). *[Note: all parameters had nine paired observations]*. A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were not significantly different for oxidation-reduction potential, nitrate-nitrite nitrogen, alkalinity, or ortho-phosphorus. Parameters that were significantly lower in the near-bottom water of Wagon Train Reservoir when hypoxia was present included: water temperature ($p < 0.001$), dissolved oxygen ($p < 0.0001$), and pH ($p < 0.0005$). Parameters that were significantly higher in the near-bottom water were total ammonia ($p < 0.05$) and total phosphorus ($p < 0.05$).

6.2.10.1.1.5 Water Clarity

6.2.10.1.1.5.1 Secchi Transparency

Figure 6.42 displays a box plot of the Secchi depth transparencies measured at the three in-reservoir monitoring sites (i.e., WAGLKND1, WAGLKML1, and WAGLKUP1) from 2008 to 2010 (note: the monitoring sites are oriented in an upstream to downstream direction). Transparencies measured at the three sites were similar (Figure 6.42).

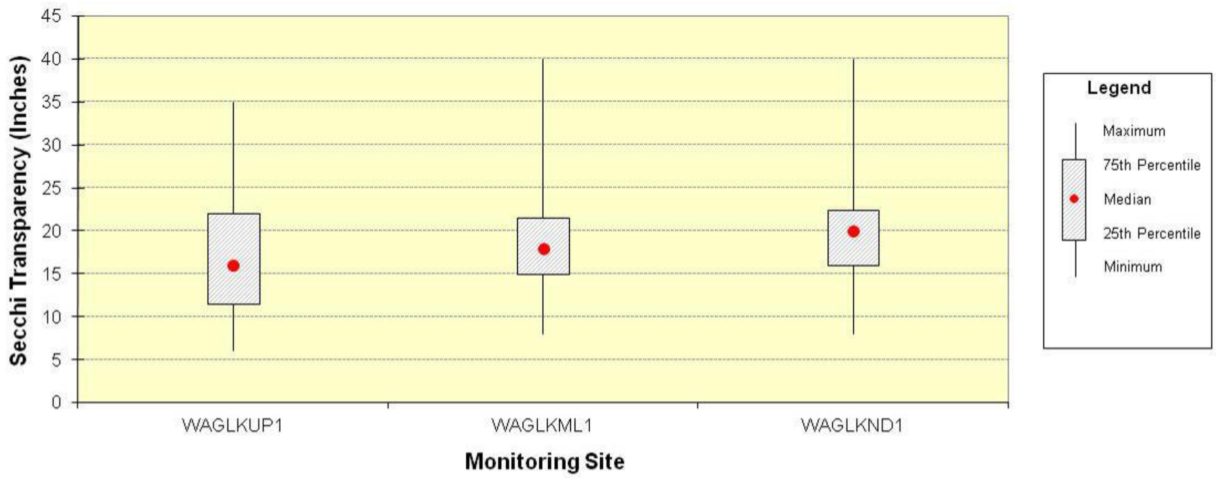

Figure 6.42. Box plot of Secchi depth transparencies measured in Wagon Train Reservoir from 2008 through 2010. (Note: monitoring sites are oriented on the x-axis in an upstream to downstream direction.)**.**

6.2.10.1.1.5.2 Turbidity

Turbidity contour plots were constructed along the length of Wagon Train Reservoir based on depth-profile measurements taken during 2009 and 2010. Plates 230 and 231, respectively, provide longitudinal turbidity contour plots based on depth-profile measurements taken from May through September. Wagon Train Reservoir occasionally exhibited appreciable longitudinal and depth variability in turbidity (Plate 231).

6.2.10.1.1.6 Reservoir Trophic Status

Trophic State Index (TSI) values for Wagon Train Reservoir were calculated from monitoring data collected during the 5-year period 2006 through 2010 at the near-dam ambient monitoring site (i.e., WAGLKND1). Table 6.27 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Wagon Train Reservoir is in a hypereutrophic condition.

Table 6.26. Summary of Trophic State Index (TSI) values calculated for Wagon Train Reservoir for the 5-year period 2006 through 2010.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	25	71	71	60	90
TSI(TP)	25	74	74	63	82
TSI(Chl)	25	71	74	50	96
TSI(Avg)	25	72	73	64	83

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values.

Note: See Section 4.1.3 for discussion of TSI calculation.

6.2.10.1.1.7 Monitoring at Swimming Beaches

A designated swimming beach is located on Wagon Train Reservoir. Bacteria (i.e., *E. coli*) and the cyanobacteria toxin microcystin were monitored at the swimming beach on the reservoir at site WAGLKBACT1 by the NDEQ (Figure 6.41). Bacteria and microcystins were monitored from May through September over the 5-year period 2006 through 2010.

6.2.10.1.1.7.1 Bacteria Monitoring

Table 6.28 summarizes the results of the *E. coli* bacteria monitoring. The "running 5-week" geometric means were calculated as running geometric means for five consecutive weekly bacteria samples through the recreational season (i.e., May through September). The "pooled" geomean was determined by pooling all the weekly bacteria samples collected during the recreational season over the 5-year period and calculating a single geomean. All nondetects were set to 1 to calculate geomeans. The sampling results were compared to the following Nebraska water quality criteria for *E. coli* bacteria:

> *E. coli* bacteria should not exceed a geometric mean of 126/100ml. For increased confidence of the criteria, the geometric mean should be based on a minimum of five samples taken within a 30-day period. Single sample maximum allowable density for designated bathing beaches is 235/100ml.

The pooled geomean was compared to the State of Nebraska's impairment assessment criteria regarding the assessment of the Primary Contact Recreation beneficial use using *E. coli* bacteria data. Based on the criteria a Primary Contact Recreation use in Wagon Train Reservoir is not impaired due to bacteria. The higher bacteria levels monitored in the reservoir are believed to be associated with runoff events.

Table 6.27. Summary of weekly (May through September) *E. coli* bacteria samples collected at Wagon Train Reservoir (i.e., site WAGLKBACT1) during the 5-year period 2006 through 2010.

***E. coli* – Individual Samples**		***E. coli* – Geomeans (Running 5-Week)**	
Number of Samples	124	Number of Geomeans	100
Mean (cfu/100ml)	89	Average	19
Median (cfu/100ml)	7	Median	14
Minimum (cfu/100ml)	1	Minimum	2
Maximum (cfu/100ml)	3076	Maximum	96
Percent of samples exceeding 235/100ml	7%	Percent of Geomeans exceeding 126/100ml	0%
		***E. coli* – Geomean (5-Year Pooled)**	
		5-Year Pooled Geomean	10

6.2.10.1.1.7.2 Microcystin Monitoring

Table 6.29 summarizes the microcystin monitoring conducted at the Wagon Train Reservoir swimming beach during the 5-year period 2006 through 2010. These results were compared to the 20 ug/l criterion for issuing health advisories and the posting of swimming beaches. No samples exceeded the criterion. The monitored levels of microcystin do not indicate a significant cyanobacteria toxin concern at Wagon Train Reservoir.

Table 6.28. Summary of weekly (May through September) microcystin samples collected at the Wagon Train Reservoir swimming beach (i.e., site WAGLKBACT1) during the 5-year period 2006 through 2010.

Summary Statistic	Swimming Beach (Site WAGLKBACT1)
Number of Samples	107
Minimum (ug/l)	< 0.2
25th percentile (ug/l)	< 0.2
Median (ug/l)	< 0.2
75th Percentile (ug/l)	< 0.2
Maximum (ug/l)	2.0
Percent of samples exceeding 20 ug/l	0%

6.2.10.1.2 Water Quality Trends (1980 through 2010)

Water quality trends from 1980 to 2010 were determined for Wagon Train Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through September at the near-dam monitoring site (i.e., WAGLKND1). Plate 232 displays a scatter-plot of the collected data for the four parameters and a monotonic linear regression lines for the periods 1980 through 1998 and 2003 through 2010. The data gap of 1998 through 2002 is the period when the lake renovation project was implemented at Wagon Train Reservoir. When several years of post-project data have been collected, analyses for step trend assessment will be pursued to test for water quality changes from "pre-project" conditions. A cursory trend analysis indicates increasing "post-project" levels of total phosphorus and chlorophyll *a*. Water transparency is decreasing to levels similar to "pre-project" conditions (Plate 232).

6.2.10.1.3 Existing Water Quality Conditions of Runoff Inflows to Wagon Train Reservoir

Existing water quality conditions in the main tributary inflow to Wagon Train Reservoir was monitored at site WAGNF1 by the NDEQ under runoff conditions during the period of April through September (Figure 6.41). Site WAGNF1 was approximately 1 mile upstream from the reservoir. Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from "base-flow" conditions. Plate 233 summarizes water quality conditions that were monitored at site WAGNF1 under runoff conditions during the 5-year period 2004 through 2008. Tributary inflows to Wagon Train Reservoir were not monitored in 2009 and 2010 (Plate 233).

6.2.11 YANKEE HILL RESERVOIR

6.2.11.1 <u>Background Information</u>

6.2.11.1.1 Project Overview

The dam forming Yankee Hill Reservoir is located on the Cardwell Branch. The dam was completed on August 27, 1963 and the reservoir reached its initial fill in May 1965. The Yankee Hill Reservoir watershed is 9.7 square miles. The watershed was largely agricultural when the dam was built in 1963 and has remained so to the present time.

6.2.11.1.2 Aquatic Habitat Improvement and Water Quality Management Project

A lake renovation project was started at Yankee Hill Reservoir in 1999 and completed in 2005. To facilitate the project, the reservoir was drawn down in 1998 and refilled in 2006. The goal of the project was to reduce the threat of winter fish kills, create more open water habitat for fish, stabilize shorelines and create fringe wetlands, reduce sediment and nutrient loading into the reservoir, manipulate water levels to promote fish production, and set back succession by restructuring the rough fish dominated fishery. Approximately $1.9 million in Federal, State, and Local funding was spent on the lake renovation project.

Included in the project were three sediment/nutrient dikes, three offshore breakwaters, three islands, five jetties, six hardpoints, seven underwater islands, modification of the outlet structure, a new boat ramp and parking lot, reservoir basin excavation, and fish renovation and restocking. Reservoir basin excavation included the excavation and disposal of 349,800 cubic yards of material beyond the reservoir's flood pool and the relocation of 95,000 cubic yards as compact fill for jetties, offshore breakwaters, and sediment dikes within the reservoir basin. Material disposed outside the flood pool has enlarged the reservoir's volume by 216.7 ac-ft, a 19 percent increase, and increased the mean depth of the reservoir from 6.4 to 7.1 feet. The three sediment dikes are expected to reduce sediment loads by 50 percent annually. Collectively, the jetties, breakwaters, and islands have added 16,135 feet of productive shoreline to the reservoir, a 79 percent increase. Fish attractors in the form of cedar trees have also been added to the reservoir. Aerial views of Yankee Hill Reservoir during construction of the lake renovation project are provided in Figure 6.43

Figure 6.43. Aerial views of Yankee Hill Reservoir during construction of the lake renovation project.

6.2.11.1.3 Yankee Hill Dam Intake Structure

The dam intake at Yankee Hill is a drop inlet structure consisting of a single reinforced concrete box shaft. Its inside dimensions are 3.5 feet by 5.25 feet. The intake structure has four ungated openings – two 18" x 63" openings with a crest elevation at 1250.0 ft-msl and two 12" x 30" openings with a crest elevation at 1244.9 ft-msl. A 36" x 36" gated opening with a crest elevation of 1237.0 ft-msl was constructed into the upstream wall. As part of the recent lake renovation project a "stop-log" structure was attached to the concrete box shaft over the 36" x 36" gated opening. The 36" x 36" gate is permanently left open and pool levels are managed with the external stop-log structure. The purpose of the gate modification is to allow for better management of pool elevations for water quality and fishery management. The gated outlet may also be used to release water for downstream needs.

6.2.11.1.4 Reservoir Storage Zones

Figure 6.44 depicts the current storage zones of Yankee Hill Reservoir based on the 1994 survey data, results of the recent lake renovation project, and estimated sedimentation. After accounting for the sediment removed from the reservoir basin as part of the recent lake renovation project, it is estimated that 11 to 15 percent of the "as-built" volume to the top of the Conservation Pool has been lost to sedimentation as of 2010. The annual volume loss, prior to the implementation of the lake renovation project, is estimated to be 0.51 percent. However, measures implemented as part of the lake renovation project (i.e., sediment/nutrient dikes) are believed to have reduced the annual volume loss. Based on the State of Nebraska's impairment assessment criteria, these values indicate that Yankee Hill Reservoir's water quality dependent uses are not impaired due to sedimentation.

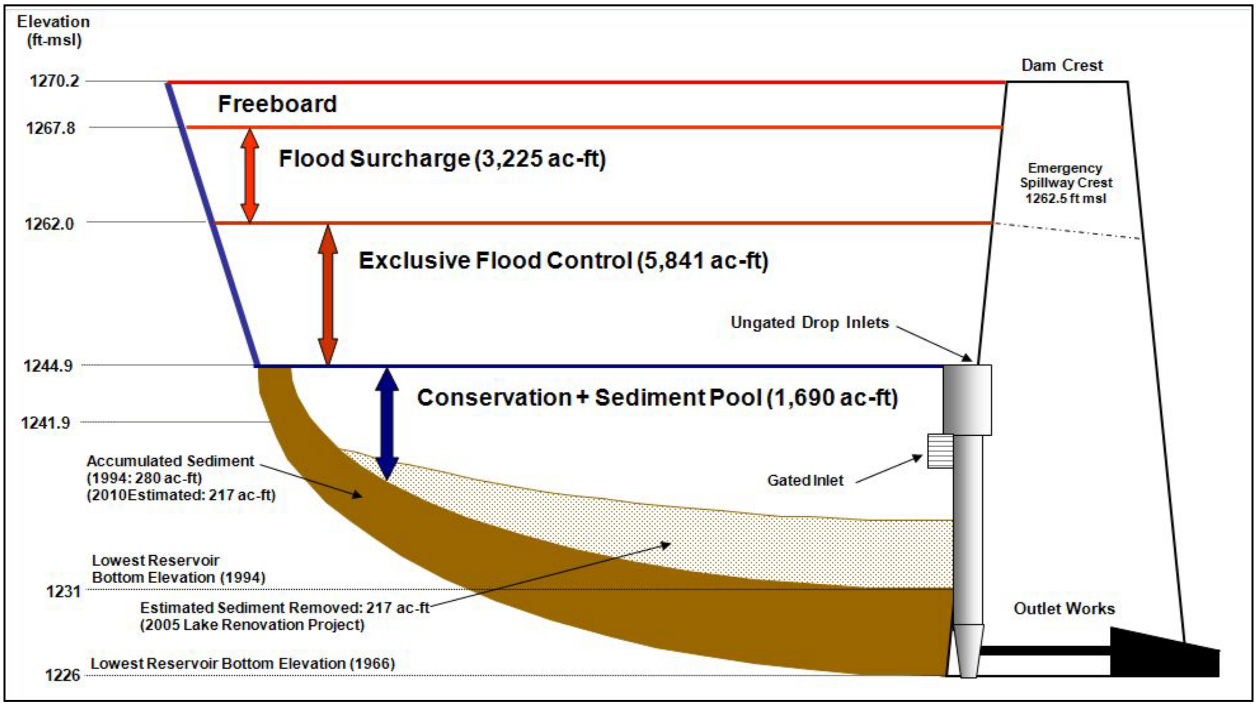

Figure 6.44. Current storage zones of Yankee Hill Reservoir based on the 1994 survey data and estimated sedimentation.

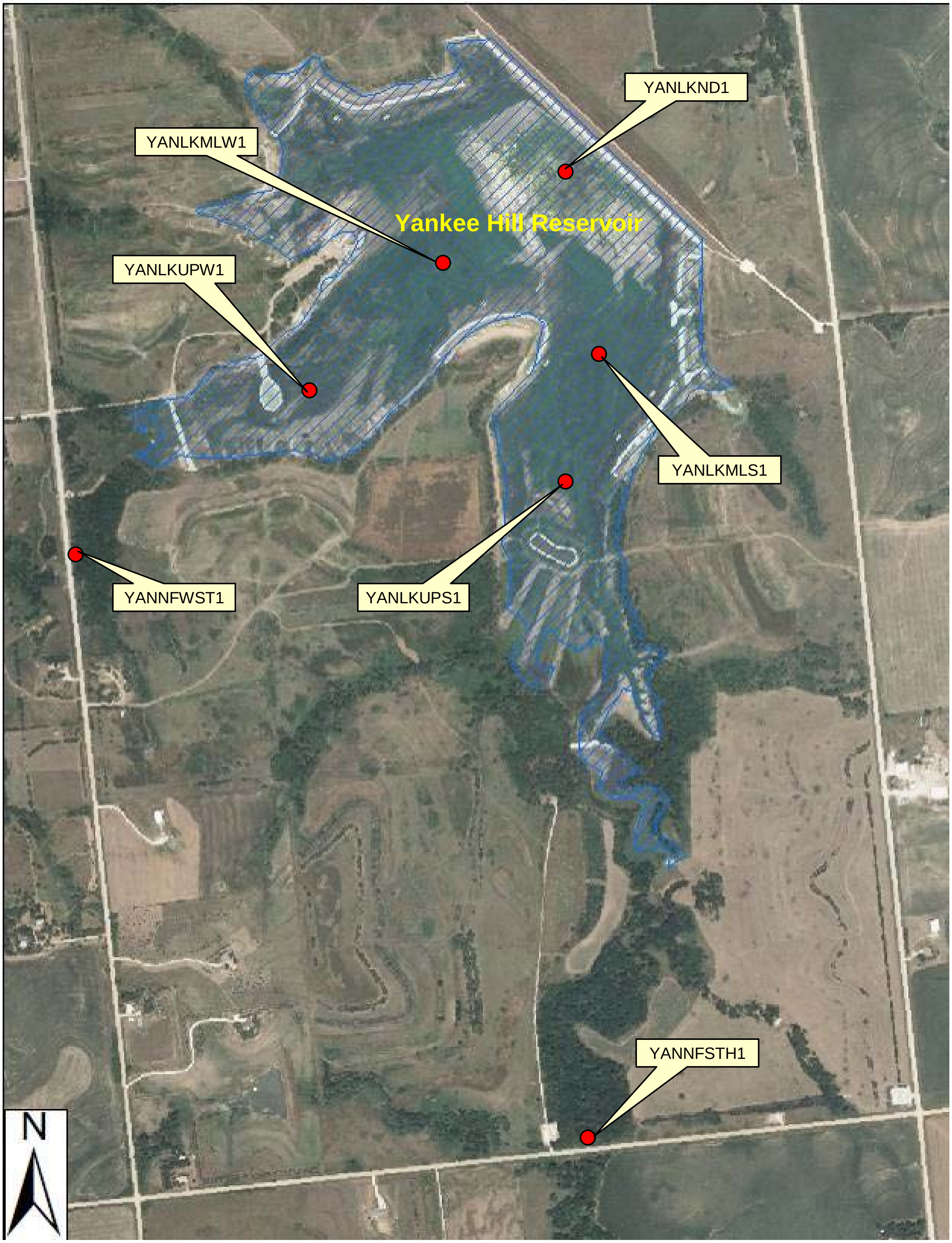

Figure 6.45. Location of sites where water quality monitoring was conducted at Yankee Hill during the period 2006 through 2010**.**

6.2.11.1.5 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Yankee Hill Reservoir since the late 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. As mentioned, a lake renovation project was implemented at Yankee Hill reservoir from 1999 through 2005. During this period the reservoir was drawn down to facilitate construction activities, and in-reservoir water quality monitoring by the District was discontinued. In-reservoir monitoring was restarted in 2007. Runoff monitoring by the NDEQ on the two main tributary inflows to the reservoir continued during the lake renovation project. Figure 6.45 shows the location of the sites that have been monitored for water quality during the past 4 years (i.e., 2007 through 2010). The near-dam location (YANLKND1) has been monitored by the District since 1980.

6.2.11.2 Water Quality in Yankee Hill Reservoir

6.2.11.2.1 Existing Water Quality Conditions

6.2.11.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Yankee Hill Reservoir at sites YANLKND1, YANLKMLW1, and YANLKMLS1 from May through September during the 4-year period 2007 through 2010 are summarized, respectively, in Plates 234, 235, and 236. A review of these results indicated possible water quality concerns regarding dissolved oxygen, pH, ammonia, selenium, and nutrients.

An appreciable number (> 14%) of dissolved oxygen measurements taken in Yankee Hill Reservoir were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plate 234). Most of the low dissolved oxygen measurements occurred near the bottom of the reservoir, and may have been associated with thermal stratification. Nebraska's Water Quality Standards makes the following provision regarding the application of the State's water quality standards' criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision may apply to the low dissolved oxygen situation in Yankee Hill Reservoir, and the measured dissolved oxygen levels below 5 mg/l may not be a water quality standards non-attainment situation.

A large number (> 19%) of pH readings measured throughout Yankee Hill Reservoir were above the numeric pH criteria of 9.0 for the protection of warmwater aquatic life (PlateS 234 - 236). A few pH measurements were also below the pH criterion of 6.5 for the protection of warmwater aquatic life (Plate 234). The lowest and highest pH levels measured were, respectively, 6.4 and 10.1. The magnitude and number of pH criterion exceedences indicate a noteworthy water quality concern. Based on the State of Nebraska's impairment assessment criteria, the percent exceedence of the upper pH criterion indicates impairment of the Aquatic Life beneficial use of Yankee Hill Reservoir. It is believed the high pH values may be associated with periods of high algal production and CO_2 uptake during photosynthesis.

The chronic ammonia criterion for the protection of warmwater aquatic life was seemingly exceeded in 1 of 16 samples (6%) collected in the area near the dam. Ammonia criteria are pH and temperature dependant, and the criteria cited are based on median values that may or may not represent conditions when the higher ammonia occurred.

One of two selenium measurements (50%) exceeded the chronic selenium criterion for the protection of aquatic life. At this time the exceedence is considered to be a possible outlier.

Nutrient criteria defined in Nebraska's water quality standards for R13 impounded waters include: total phosphorus (50 ug/l), total nitrogen (1,000 ug/l), and chlorophyll *a* (10 ug/l). All three of these criteria were exceeded throughout Yankee Hill Reservoir (PlateS 234 - 236). The total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 100, 97, and 100 percent of the samples collected at site YANLKND1. All the samples were collected during the "growing season" (i.e., May through September) and the reported mean values represent the growing season average for the 4-year period 2007 through 2010. Based on the State of Nebraska's impairment assessment criteria, the mean values for the three parameters and the exceedences of the dissolved oxygen and pH criteria (Plate 234) indicate impairment of the Aquatic Life beneficial use of Yankee Hill Reservoir due to nutrients.

6.2.11.2.1.2 Thermal Stratification

6.2.11.2.1.2.1 <u>Longitudinal Temperature Contour Plots</u>

Late-spring and summer thermal conditions of Yankee Hill Reservoir measured during 2009 and 2010 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir through the south arm. Plates 237 and 238, respectively, provide longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites YANLKND1, YANLKMLS1, and YANLKUPS1 in 2009 and 2010. These temperature plots indicate that Yankee Hill Reservoir regularly exhibited significant thermal stratification during the 2-year period. The maximum difference monitored between the surface and bottom water temperatures during the 2-year period was 7°C in June of 2009 (Plate 237).

6.2.11.2.1.2.2 <u>Near-Dam Temperature Depth-Profile Plots</u>

Existing summer thermal stratification of Yankee Hill Reservoir, at the deep water area near the dam, measured over the 4-year period 2007 through 2010 is depicted by depth-profile temperature plots (Plate 239). The depth-profile temperature plots indicate that the reservoir regularly exhibited significant summer thermal stratification over the past 4 years. Since Yankee Hill Reservoir ices over in the winter and seemingly exhibits periodic circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

6.2.11.2.1.3 Summer Dissolved Oxygen Conditions

6.2.11.2.1.3.1 <u>Longitudinal Dissolved Oxygen Contour Plots</u>

Dissolved oxygen contour plots were constructed along the length of Yankee Hill Reservoir through the south arm based on depth-profile measurements taken during 2009 and 2010 at sites YANLKND1, YANLKMLS1, and YANLKUPS1. Plates 240 and 241, respectively, provide longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September in 2009 and 2010. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored along the reservoir bottom near the dam in both years (Plates 240 and 241). Super-saturation of dissolved oxygen was also monitored in shallow water areas (Plates 240 and 241). Dissolved oxygen super-saturation was attributed to high rates of photosynthesis by aquatic vegetation in the reservoir during the day (see discussion of pH monitoring in Section 7.1.11.2.1.4.2).

6.2.11.2.1.3.2 <u>Near-Dam Dissolved Oxygen Depth-Profile Plots</u>

Existing summer dissolved oxygen conditions in Yankee Hill Reservoir are described by the dissolved oxygen depth-profiles measured near the dam over the 4-year period 2007 through 2010.

Summer dissolved oxygen depth-profiles were compiled and plotted for the 4 years (Plate 242). On most occasions there was a significant vertical gradient in summer dissolved oxygen levels. Both hypoxic conditions near the reservoir bottom and super-saturation near the surface were monitored (Plate 242). Although Yankee Hill Reservoir appears to be polymictic there appears to be enough inhibition to mixing to allow hypoxic conditions to develop near the reservoir bottom.

6.2.11.2.1.3.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of Yankee Hill Reservoir with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2009 and 2010 and the District's current Area-Capacity Tables (1994 Survey) for the reservoir. The constructed contour plots were reviewed to identify the "worst-case" dissolved oxygen condition. The "worst-case" condition was taken to be the contour plot with the highest elevations of the 5 mg/l and 2.5 mg/l dissolved oxygen isopleths. The August 11, 2010 contour plot indicates a pool elevation of 1245.2 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1237.0 ft msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1236.0 ft-msl (Plate 241). The District's Area-Capacity Tables give storage capacities of 1,694 ac-ft for elevation 1245.2 ft-msl, 392 ac-ft for elevation 1237.0 ft-msl, and 293 ac-ft for elevation 1236.0 ft-msl. On August 11, 2010 it is estimated that 23 percent of the volume of Wagon Train Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 17 percent of the reservoir volume was hypoxic.

6.2.11.2.1.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in Yankee Hill Reservoir indicated hypoxic conditions were present during the summers of 2009 and 2010, longitudinal contour and depth-profile plots were constructed for ORP and pH. Near-surface and near-bottom water quality samples collected when hypoxia was present were also compared.

6.2.11.2.1.4.1 Oxidation-Reduction Potential

Plates 243 and 244, respectively, provide longitudinal ORP contour plots based on depth-profile measurements taken in 2009 and 2010. The ORP values indicated slightly reduced conditions occurred near the reservoir bottom on occasions when hypoxic conditions were monitored (Plates 243 and 244). Plate 245 plots depth profiles for ORP measured during the 4-year period 2007 through 2010 in the deep water area of Yankee Hill Reservoir near the dam. The ORP depth profiles indicate that appreciable reduced conditions regularly occurred near the bottom of Yankee Hill Reservoir during the summer (Plate 245).

6.2.11.2.1.4.2 pH

Longitudinal contour plots for pH conditions measured in 2009 and 2010 are provided, respectively, in Plates 246 and 247. Plate 248 plots depth profiles for pH levels measured during the summer over the 4-year period 2007 through 2010 in the deep water area of Yankee Hill Reservoir near the dam. An appreciable vertical gradient in pH regularly occurred in the reservoir during the summer (Plates 246 - 248). It appears reduced conditions in the deeper water of Yankee Hill Reservoir seemingly resulted in lower pH levels near the reservoir bottom, while "hyper" photosynthesis resulted in higher pH levels near the reservoir surface. The lowest and highest measured pH levels exceeded the lower pH criterion of 6.5 and the upper pH criterion of 9.0 for the protection of warmwater aquatic life.

6.2.11.2.1.4.3 Comparison of Near-Surface and Near-Bottom Water Quality Conditions

Paired near-surface and near-bottom water quality samples collected from Yankee Hill Reservoir during the summer when hypoxia was present were compared. Near-surface conditions were represented by samples collected within 1-meter of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site YANLKND1 during the 4-year period 2007 through 2010. During the 4-year period a total of 18 paired samples were collected monthly from May through September. Of the 18 paired samples collected, 8 (44%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature (8), dissolved oxygen (8), oxidation-reduction potential (8), pH (8), alkalinity (6), total ammonia (6), nitrate-nitrate nitrogen (6), total phosphorus (6), and orthophosphorus (6) (Plate 249) *[Note: the number in parentheses is the number of paired observations available for each parameter]*. A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were not found to be significantly different for nitrate-nitrite nitrogen. Parameters that were found to be significantly lower in the near-bottom water of Yankee Hill Reservoir when hypoxia was present included: water temperature ($p < 0.0005$), dissolved oxygen ($p < 0.0001$), oxidation-reduction potential ($p < 0.01$), and pH ($p < 0.0005$). Parameters found to be significantly higher in the near-bottom water of Yankee Hill Reservoir when hypoxia was present included: total ammonia ($p < 0.005$), alkalinity ($p < 0.005$), total phosphorus ($p < 0.05$), and orthophosphorus ($p < 0.05$).

6.2.11.2.1.5 Water Clarity

6.2.11.2.1.5.1 Secchi Transparency

Figure 6.46 displays a box plot of the Secchi depth transparencies measured at the five in-reservoir monitoring sites (i.e., YANLKND1, YANLKMLS1, YANLKMLW1, YANLKUPS1, and YANLKUPW1) from 2008 to 2010 (note: the monitoring sites are oriented in an upstream to downstream direction). Transparencies measured at the five sites were all similar (Figure 6.46).

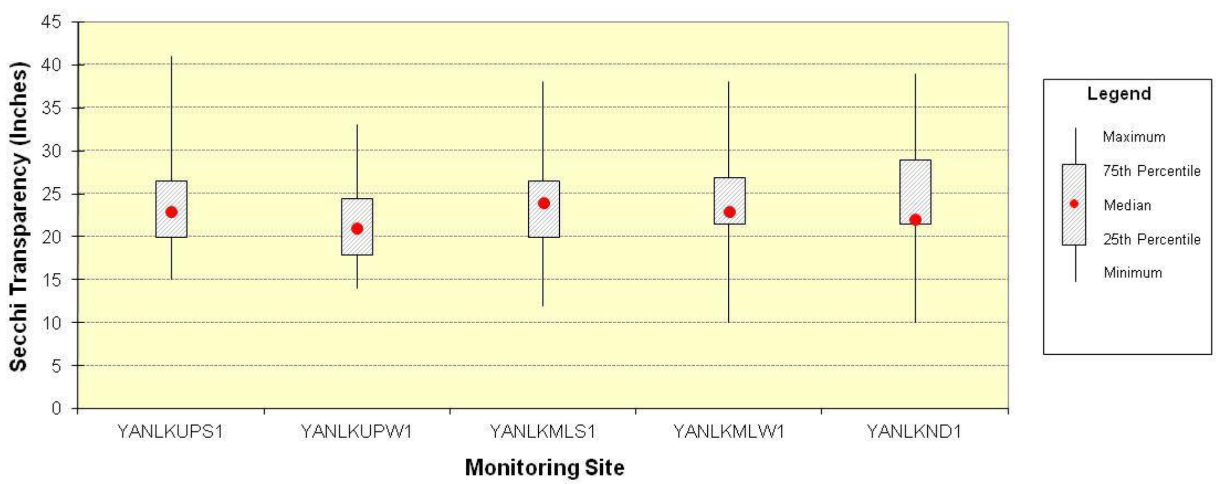

Figure 6.46. Box plot of Secchi depth transparencies measured in Wagon Train Reservoir from 2008 to 2010. (Note: monitoring sites are oriented on the x-axis in an upstream to downstream direction.)

6.2.11.2.1.5.2 Turbidity

Turbidity contour plots were constructed along the length of Yankee Hill Reservoir through the south arm based on depth-profile measurements taken during 2009 and 2010. Plates 250 and 251, respectively, provide longitudinal turbidity contour plots based on depth-profile measurements taken from May through September. Yankee Hill Reservoir occasionally exhibited appreciable longitudinal and depth variability in turbidity (Plates 250 and 251).

6.2.11.2.1.6 Reservoir Trophic Status

Trophic State Index (TSI) values for Yankee Hill Reservoir were calculated from monitoring data collected during the 4-year period 2009 through 2010 at the near-dam ambient monitoring site (i.e., YANLKND1). Table 6.30 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Yankee Hill Reservoir is in a hypereutrophic condition.

Table 6.29. Summary of Trophic State Index (TSI) values calculated for Yankee Hill Reservoir for the 4-year period 2007 through 2010.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	18	67	68	60	80
TSI(TP)	18	72	74	63	80
TSI(Chl)	18	76	76	63	87
TSI(Avg)	18	72	72	64	81

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values.

Note: See Section 4.1.3 for discussion of TSI calculation.

6.2.11.2.2 Water Quality Trends (1980 through 2010)

Water quality trends from 1980 to 2010 were determined for Yankee Hill Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through October at the near-dam monitoring site (i.e., YANLKND1). Plate 252 displays a scatter-plot of the collected data for the four parameters and a monotonic linear regression lines for the periods 1980 through 1998 and 2007 through 2010. The data gap of 1998 through 2006 is the period when the lake renovation project was implemented at Yankee Hill Reservoir. When several years of post-project data has been collected, analyses for step trend assessment will be pursued to test for water quality changes from “pre-project” conditions. A cursory trend analysis indicates decreasing “post-project” levels of total phosphorus and chlorophyll *a* and increasing water transparency (Plate 252).

6.2.11.2.3 Existing Water Quality Conditions of Runoff Inflows to Yankee Hill Reservoir

Existing water quality conditions in the main tributary inflows to Yankee Hill Reservoir were monitored by the NDEQ under runoff conditions, during the period of April through September, at two sites YANNFWST1 and YANNFSTH1 (Figure 6.45). Both sites were about ¼ mile upstream from the reservoir. Runoff conditions were considered to be a 1-inch rainfall event or a 6-inch or more rise in stream stage from “base-flow” conditions. Plates 253 and 254, respectively, summarize water quality conditions that were monitored at sites YANNFWST1 and YANNFSTH1 under runoff conditions during the period 2004 through 2008. Tributary inflows to Yankee Hill Reservoir were not monitored in 2009 and 2010.

6.3 SUMMARY OF WATER QUALITY CONDITIONS MONITORED AT THE NEBRASKA TRIBUTARY PROJECTS

6.3.1 EXCEEDENCES OF NUMERIC WATER QUALITY STANDARDS CRITERIA

Table 6.31 presents a summary of the exceedences of State water quality standards that occurred at the Papillion and Salt Creek Tributary Project reservoirs based on water quality monitoring conducted over the 5-year period of 2004 through 2008. Except for *E. coli* and microcystin, the percentages presented in Table 6.30 represent the number of exceedences that occurred at the near-dam, deepwater ambient monitoring site. For *E. coli* and microcystin, samples were collected at designated swimming beaches or areas of high recreational use. Results for dissolved oxygen and pH are for water column profile measurements. Results for chlorophyll *a*, atrazine, aluminum, selenium, *E. coli*, and microcystin are for "grab samples" collected near the reservoir surface. Results for total nitrogen, total ammonia, and total phosphorus are for "grab samples" collected at near-surface and near-bottom depths.

Table 6.30. Percent exceedences of water quality standards criteria for all samples collected at near-dam, deepwater monitoring sites during the 5-year period of 2006 through 2010. (Note: *E. coli* and microcystin samples were collected at designated swimming beaches or areas of high recreational use.)

	Dissolved Oxygen (<5 mg/l)	**pH** (> 9 SU)	**Total Ammonia** (Variable)(1)	**Total Nitrogen** (>1.0 mg/l)(2)	**Total Phosphorus** (>50 ug/l)(3)	**Chlorophyll *a*** (>10 ug/l)(4)	**Atrazine** (>12 ug/l)	**Aluminum** (>87 ug/l)	**Arsenic** (>16.7 ug/l)	**Mercury** (>1.4 ug/l) (>.77 ug/l)	**Selenium** (>5 ug/l)	***E. coli*(5)** (>126/100ml)(6) (>235/100ml)(7)	**Microcystin(7)** (>20 ug/l)
Papillion Creek Reservoirs													
Ed Zorinsky	30%	0%	2%	60%	78%	72%	0%	20%	0%	0%	0%	-----	-----
Glenn Cunningham	40%	0%	0%	72%	72%	100%	0%	0%	0%	0%	0%	0% 5%	-----
Standing Bear	38%	1%	10%	68%	70%	69%	0%	0%	0%	0% 20%	0%	-----	-----
Wehrspann	31%	0%	2%	72%	90%	72%	0%	0%	0%	0%	0%	-----	-----
Salt Creek Reservoirs													
Bluestem	11%	0%	0%	92%	100%	55%	0%	0%	0%	0%	20%	18% 16%	1%
Branched Oak	16%	0%	2%	68%	82%	72%	0%	0%	0%	0%	0%	3% 9%	0%
Conestoga	15%	1%	0%	96%	98%	75%	0%	0%	0%	0%	20%	1% 3%	3%
East Twin	20%	3%	4%	100%	90%	80%	0%	0%	0%	0%	20%	-----	-----
Holmes	19%	18%	6%	69%	94%	73%	0%	0%	0%	0%	20%	6% 13%	1%
Olive Creek	15%	39%	6%	95%	100%	76%	0%	0%	60%	0%	20%	-----	-----
Pawnee	18%	8%	4%	92%	92%	80%	0%	0%	0%	0%	20%	7% 10%	35%
Stagecoach	23%	0%	0%	100%	98%	46%	4%	0%	0%	0%	0%	-----	-----
Wagon Train	35%	0%	4%	94%	100%	76%	0%	20%	20%	0%	20%	0% 5%	0%
Yankee Hill	20%	18%	11%	97%	100%	100%	0%	0%	0%	0%	25%	-----	-----

(1) Total ammonia criteria are pH and temperature dependent. Percent exceedence based on median pH and temperature conditions and may not represent conditions when total ammonia was measured.
(2) Total nitrogen criteria defined for R13 and R18 categorized lakes (1.0 mg/l).
(3) Total phosphorus criteria defined for R13 and R18 categorized lakes (50 ug/l).
(4) Chlorophyll *a* criteria defined for R13 and R18 categorized lakes (10 ug/l).
(5) Samples collected at designated swimming beaches or areas of heavy recreational use.
(6) Criterion is for geometric mean of 5 samples collected within a 30-day period.
(7) Criterion is for an individual observation.

6.3.2 WATER CLARITY

Figure 6.47 presents a box plot of Secchi depths recorded at the Papillion and Salt Creek Tributary Project reservoirs over the 5-year period of 2006 through 2010. Bluestem Reservoir had the lowest Secchi depth measurements and Glenn Cunnigham and Branched Oak Reservoirs had the greatest.

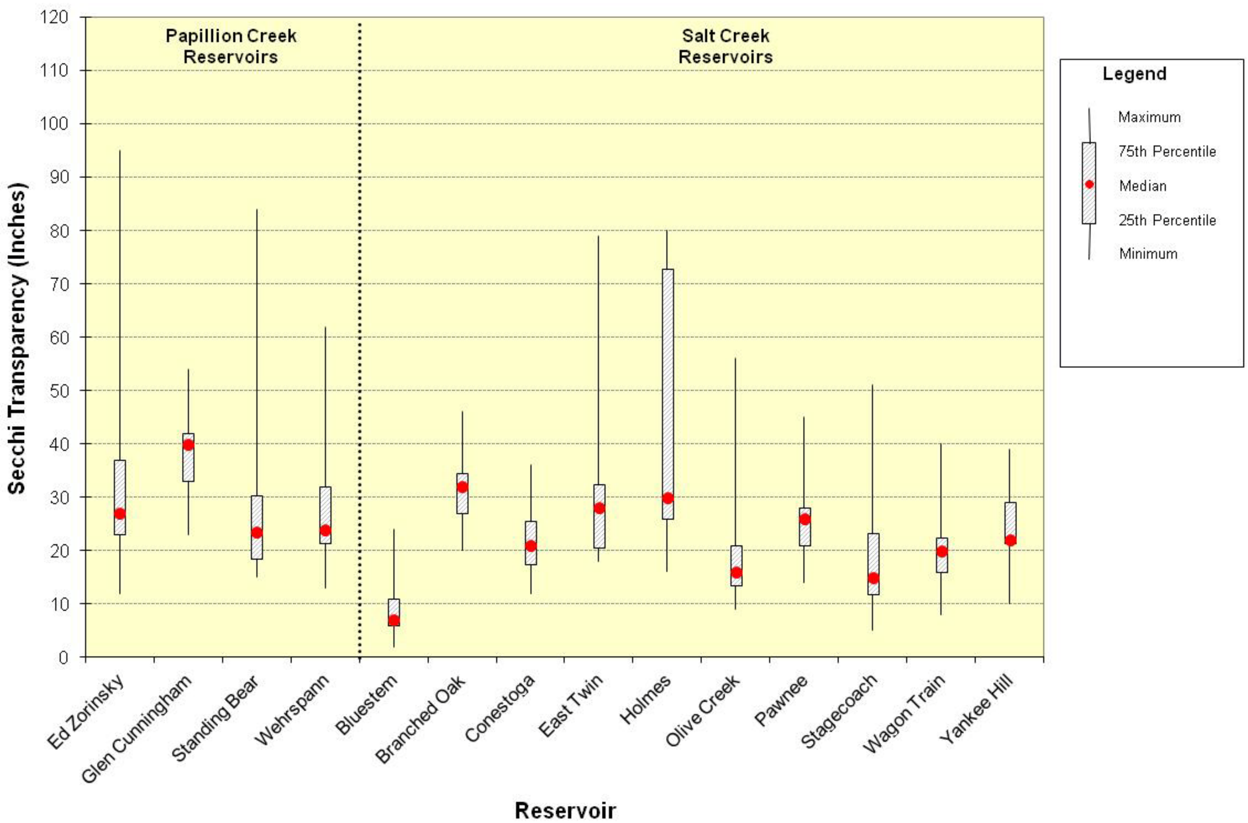

Figure 6.47. Box plot of Secchi depths measured at the Papillion and Salt Creek Tributary Project reservoirs during the 5-year period 2006 through 2010.

6.3.3 TROPHIC CONDITION

Figure 6.48 presents a box plot of Trophic State Index (TSI) values calculated for the Papillion and Salt Creek tributary reservoirs. The TSI values are based on Secchi depth, total phosphorus, and chlorophyll *a* levels monitored at the reservoirs over the 5-year period of 2006 through 2010. TSI values were calculated as described by Carlson (1977). Median TSI values determined for Glenn Cunningham and Ed Zorinsky reservoirs indicate a eutrophic condition. Median TSI values for the other reservoirs (i.e., Standing Bear, Wehrspann, Bluestem, Branched Oak, Conestoga, East Twin, Holmes, Olive Creek, Pawnee, Stagecoach, Wagon Train, and Yankee Hill) indicate that they are in a hypereutrophic condition.

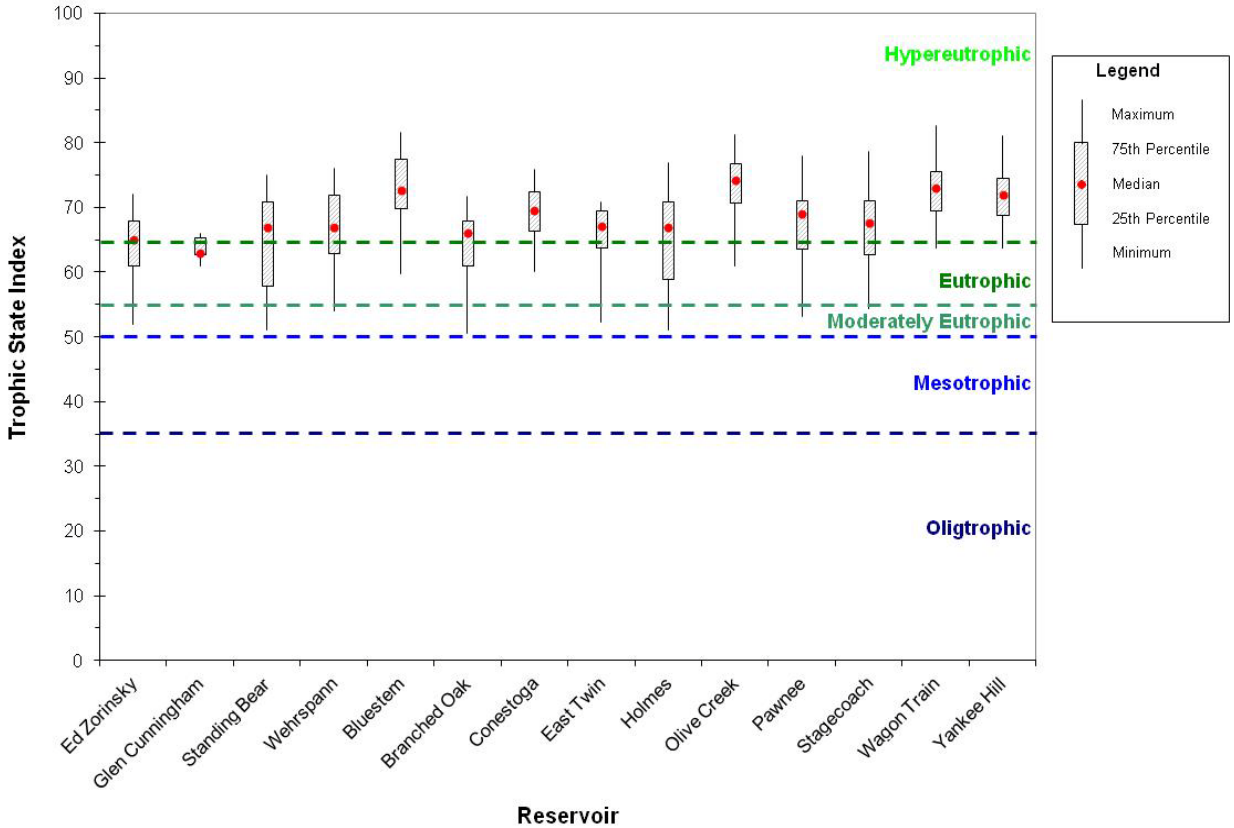

Figure 6.48. Box plot of Trophic State Index values calculated for the Papillion and Salt Creek Tributary Project reservoirs based on Secchi depth, total phosphorus, and chlorophyll *a* levels measured in the area near the dam over the 5-year period of 2006 through 2011.

6.3.4 SEDIMENTATION

Estimated sedimentation at the Papillion and Salt Creek Tributary Project reservoirs, as of 2010, is presented in Figure 6.49. Figure 6.49 gives the estimated volume loss of the Conservation plus Sediment Pool volume from "as-built" conditions. Some of the reservoirs do not have a Conservation Pool allocated. In all cases, the pool volume loss represented is the estimated loss of the pool volume below the ungated drop inlet crest elevation.

6.3.5 IMPAIRED WATERBODIES

The Papillion and Salt Creek Tributary Project reservoirs that are believed to be impaired based on water quality conditions monitored by the District over the 5-year period of 2006 through 2011 are respectively presented in Tables 6.32 and 6.33. The tables list the reservoir, impaired beneficial use, parameters for which water quality criteria are exceeded, and pollutants of concern. Impairments were identified by applying the criteria used by the State of Nebraska to develop their 2010 Integrated Water Quality Report. It is noted that the "official" determination of whether the Papillion and Salt Creek Tributary Project reservoirs are impaired, pursuant to the Federal CWA, is by the State of Nebraska pursuant to their Section 305(b) and Section 303(d) assessments compiled in their Integrated Water Quality Report (See Table 1.3).

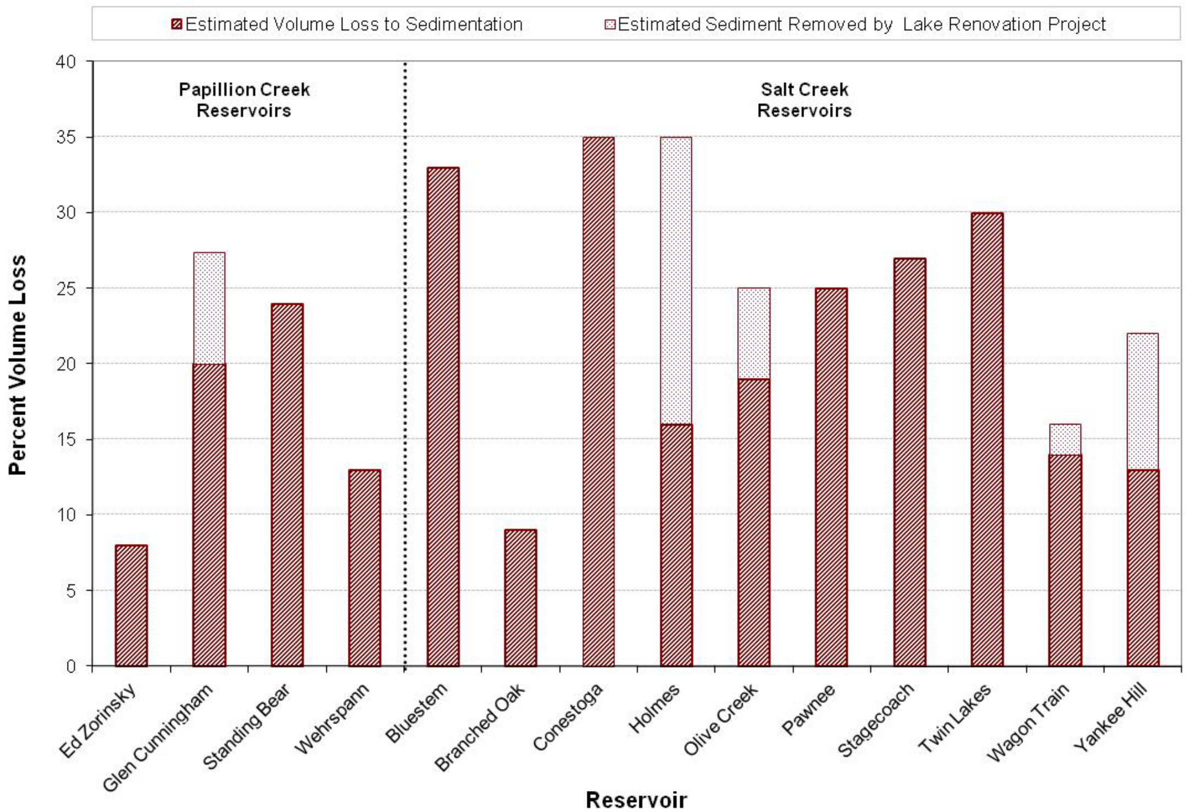

Figure 6.49. Estimated volume loss of the Conservation plus Sediment Pool volume (i.e., pool volume below the ungated drop inlet crest elevation) from "as-built" conditions as of 2010.

Table 6.31. Papillion Creek Tributary Project reservoirs which are believed to be impaired based on current water quality monitoring data and 2010 impairment assessment criteria identified by the State of Nebraska.

Reservoir	Impaired Beneficial Use	Criteria Exceeded
Ed Zorinsky	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen) Mercury (Fish Tissue)
Glen Cunningham*	-----	-----
Standing Bear	Aesthetics Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Mercury (Fish Tissue), Sediment
Wehrspann	Aesthetics	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Mercury (Fish Tissue)

*Category 4R – Waterbody data exceeds the impairment threshold however a TMDL may not be needed. The category will only be used for nutrient assessments in new or renovated lakes and reservoirs. Newly filled reservoirs usually go through a period of trophic instability – a trophic upsurge followed by the trophic decline. Erroneous water quality assessments are likely to occur during this period. To account for this, all new orrenovated reservoirs will be placed in this category for a period not to exceed eight years following the fill or re-fill process. After the eighth year monitoring data will be assessed and the waterbody will be appropriately placed into category 1, 2, or 5.

Table 6.32. Salt Creek Tributary Project reservoirs which are believed to be impaired based on current water quality monitoring data and 2010 impairment assessment criteria identified by the State of Nebraska.

Reservoir	Impaired Beneficial Use	Criteria Exceeded
Bluestem	Aquatic Life, Aesthetics	Sediment, Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)
Branched Oak	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)
Conestoga	Aquatic Life, Recreation	Algae Toxins, Sediment, Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)
Holmes*	-----	-----
Olive Creek	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Ammonia, Arsenic, High pH, Low Dissolved Oxygen
Pawnee	Aquatic Life, Aesthetics, Recreation	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Algae Toxins, Arsenic, Sediment
Stagecoach	Aquatic Life, Aesthetics	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Sediment
Twin Lakes	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen)
Wagon Train	Aquatic Life	Nutrients (Chlorophyll-a, Total Phosphorus, Total Nitrogen), Arsenic, Mercury (Fish Tissue)
Yankee Hill*	-----	-----

*Category 4R – Waterbody data exceeds the impairment threshold however a TMDL may not be needed. The category will only be used for nutrient assessments in new or renovated lakes and reservoirs. Newly filled reservoirs usually go through a period of trophic instability – a trophic upsurge followed by the trophic decline. Erroneous water quality assessments are likely to occur during this period. To account for this, all new orrenovated reservoirs will be placed in this category for a period not to exceed eight years following the fill or re-fill process. After the eighth year monitoring data will be assessed and the waterbody will be appropriately placed into category 1, 2, or 5.

6.3.6 WATER QUALITY TRENDS

Water quality trends (i.e., linear regression) observed for transparency (i.e., Secchi Depth), total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) for the period of 1980 through 2010 at the Papillion and Salt Creek Tributary Project reservoirs are presented in Table 6.31. Based on water quality monitoring conducted at the near-dam, deepwater ambient monitoring site.

Table 6.33. Observable trends in transparency, total phosphorus, chlorophyll *a*, and trophic state index (TSI) based on monitoring conducted over the 31-year period of 1980 through 2010.

Reservoir	Transparency	Total Phosphorus	Chlorophyll *a*	TSI
Papillion Creek Reservoirs:				
Ed Zorinsky	Decreasing	None	Increasing	Increasing
Standing Bear	None	None	Increasing	None
Wehrspann	Decreasing	Decreasing	Increasing	Increasing
Salt Creek Reservoirs:				
Bluestem	Decreasing	Increasing	None	None
Branched Oak	Decreasing	Increasing	Increasing	Increasing
Conestoga	None	Increasing	Increasing	Increasing
East Twin	Increasing	None	None	None
Pawnee	Increasing	Increasing	Increasing	None
Stagecoach	None	None	None	None

Note: Trends are not given for Glenn Cunningham, Holmes, Olive Creek, Wagon Train, and Yankee Hill Reservoirs. Lake renovations projects have recently been completed at these reservoirs.

7 NORTH DAKOTA TRIBUTARY PROJECTS

Two District Tributary Projects are located in North Dakota: Bowman-Haley and Pipestem. Bowman-Haley Reservoir is located in southwest North Dakota along the South Dakota border (Figure 1.1). Pipestem Reservoir is located in southeast North Dakota (Figure 1.1). Table 7.1 gives selected engineering data for the Bowman-Haley and Pipestem Projects.

7.1 BOWMAN-HALEY RESERVOIR

7.1.1 BACKGROUND INFORMATION

7.1.1.1 Project Overview

The dam forming Bowman-Haley Reservoir is located on the North Fork of the Grand River, 6 miles west of Haley, North Dakota. The dam was completed in August 1966 and the reservoir reached its initial fill in March 1969. The Bowman-Haley Reservoir watershed is 446 square miles. The watershed was largely agricultural and rangeland when the dam was built in 1966 and has remained so to the present time. The authorized project purposes of Bowman-Haley Reservoir are flood control, recreation, fish and wildlife, water quality, and water supply.

7.1.1.2 Bowman-Haley Dam Intake Structure

The intake structure at Bowman-Haley Dam is a shaft with a fixed weir for automatic release of water when the reservoir level rises above elevation 2754.8 ft-msl. The ungated glory hole has a crest elevation of 2754.8 ft-msl. Provision for low-level release of water is by means of a 30-inch gated pipe located in the dry well part of the intake. A 30-inch diameter slide gate is provided in the wet well as an emergency closure of the 30-inch pipe. The invert elevation for the low-level gate is 2740.0 ft-msl.

7.1.1.3 Reservoir Storage Zones

Two storage zones are provided in the reservoir, a multiple-purpose zone and a flood control zone. The multipurpose zone of 18,765 ac-ft includes storage for water supply, fish and wildlife, and recreation. In addition this zone contains space for storing an estimated 100 years of sediment deposition. The water supply storage was developed for maximum possible yield from the contributing drainage areas. Figure 7.1 depicts the current storage zones of Bowman-Haley Reservoir based on the 1984 survey data.

7.1.1.4 Water Quality Standards Classifications, Section 303(d) Listings, and Fish Consumption Advisories

The State of North Dakota has designated Bowman-Haley Reservoir as a Class 3 lake in the State's water quality standards. The beneficial uses designated for Class I streams are also applicable to all classified lakes in North Dakota. As such, the beneficial uses designated for Bowman-Haley Reservoir are: primary contact recreation, warmwater fishery, wildlife, and agricultural water supply. Water quality is also to be suitable for municipal or domestic use after appropriate treatment. The reservoir is not directly used as a municipal or domestic water supply. Pursuant to the Federal CWA, the State of North Dakota has not listed Bowman-Haley Reservoir on the State's Section 303(d) list. The State of North Dakota has issued a statewide fish consumption advisory for mercury. As such, the advisory applies to Bowman-Haley Reservoir.

Table 7.1. Summary of selected engineering data for the Bowman-Haley and Pipestem Projects.

	Bowman-Haley Reservoir	**Pipestem Reservoir**
General		
Dammed Stream	North Fork Grand River	Pipestem Creek
Drainage Area	446 sq. mi.	594 sq. mi.
Reservoir Length[1]	2.5 miles	5.5 miles
Multipurpose Pool Elevation (Top)	2754.8 ft-msl	1442.4 ft-msl
Date of Dam Closure	August 1966	July 1973
Date of Initial Fill[2]	March 1969	May 1974
"As-Built" Conditions[3]	(Project Operation and Maintenance Manual)	(1973 Survey Data)
Lowest Reservoir Bottom Elevation	2715 ft-msl	1407 ft-msl
Surface Area at top of Multipurpose Pool	1750 ac	840
Capacity to top of Multipurpose Pool	24,060 ac-ft	9,106 ac-ft
Mean Depth at top of Multipurpose Pool[4]	13.7 ft	10.8 ft
Latest Surveyed Conditions	(1984 Survey Data)	(2002 Survey Data)
Lowest Reservoir Bottom Elevation	2721 ft-msl	1414 ft-msl
Surface Area at top of Multipurpose Pool	1750 ac	845 ac
Capacity of Multipurpose Pool	18,765	8,509 ac-ft
Mean Depth at top of Multipurpose Pool[4]	10.7	10.1 ft
Sediment Deposition in Multipurpose Pool		
Historic Sediment Deposition[5]	Unknown[9]	597 ac-ft
Annual Sedimentation Rate[6]	Unknown[9]	1973-2002 19.9 ac-ft/yr
Current Estimated Sediment Deposition[7]	Unknown[9]	736 ac-ft
Current capacity of Multipurpose Pool[8]	Unknown[9]	8,370 ac-ft
Percent of "As-Built" Multipurpose Pool capacity lost to current estimated sediment deposition	Unknown[9]	8%
Operational Details – Historic	(1970 – 2010)	(1975 – 2010)
Maximum Recorded Pool Elevation	2762.7 ft-msl 28-Mar-78	1492.2 ft-msl 24-Apr-09
Minimum Recorded Pool Elevation	2723.0 ft-msl 2-Mar-67	1420.1 ft-msl 1-Mar-74
Maximum Recorded Daily Inflow	5,310 cfs 27-Mar-78	9,232 cfs 15-Apr-09
Maximum Recorded Daily Outflow	2,390 cfs 28-Mar-78	1,422 cfs 10-May-09
Average Annual Pool Elevation	2752.8 ft-msl	1447.6ft-msl
Average Annual Inflow	23,174 ac-ft	55,827 ac-ft
Average Annual Outflow	17,984 ac-ft	50,684 ac-ft
Estimated Retention Time[10]	1.04 Years	0.17 Years
Operational Details – Current[11]		
Maximum Recorded Pool Elevation	2756.1 ft-msl 4-Apr-10	1474.7 ft-msl 14-Apr-10
Minimum Recorded Pool Elevation	2751.5 ft-msl 14-Sep-10	1441.6 ft-msl 29-Sep-10
Maximum Recorded Daily Inflow	458 cfs 25-Mar-10	2070 cfs 20-Mar-10
Maximum Recorded Daily Outflow	283 cfs 5-Apr-10	614 cfs 5-Apr-10
Total Inflow (% of Average Annual)	30,950 ac-ft (141%)	118,629 ac-ft (238%)
Total Outflow (% of Average Annual)	27,154 ac-ft (163%)	115,221 ac-ft (250%)
Outlet Works		
Ungated Outlets	Glory Hole 2754.8 ft-msl	Drop Inlet 1442.5 ft-msl
Gated Outlets (Mid-depth)		2) 4'x 7' Service Gates
Gated Outlets (Low-level)	1) 30" Dia. Gate Valve 2740.0 ft-msl	1) 3'x 3' Slide Gate 1433.0 ft-msl 1) 3' Dia. Gate Valve 1415.0 ft-msl

(1) Reservoir length at top of conservation pool.
(2) First occurrence of reservoir pool elevation to top of multipurpose pool elevation.
(3) "As-Built" conditions taken to be the conditions present when the reservoir was first surveyed.
(4) Mean Depth = Volume ÷ Surface Area.
(5) Difference in reservoir storage capacity to top of Multipurpose Pool between "as-built" and latest survey.
(6) Annualized rate based on historic accumulated sediment.
(7) Current accumulated sediment estimated from historic annual sedimentation rate.
(8) Current capacity of Multipurpose Pool = "As-Built" Multipurpose Pool capacity - Estimated Current Sedimentation.
(9) Estimating "as-built" conditions from O&M manual not deemed reliable.
(10) Estimated Retention Time = Multipurpose Pool Volume ÷ Average Annual Outflow.
(11) Current operational details are for the water year 1-Oct-2009 through 30-Sep-2010.

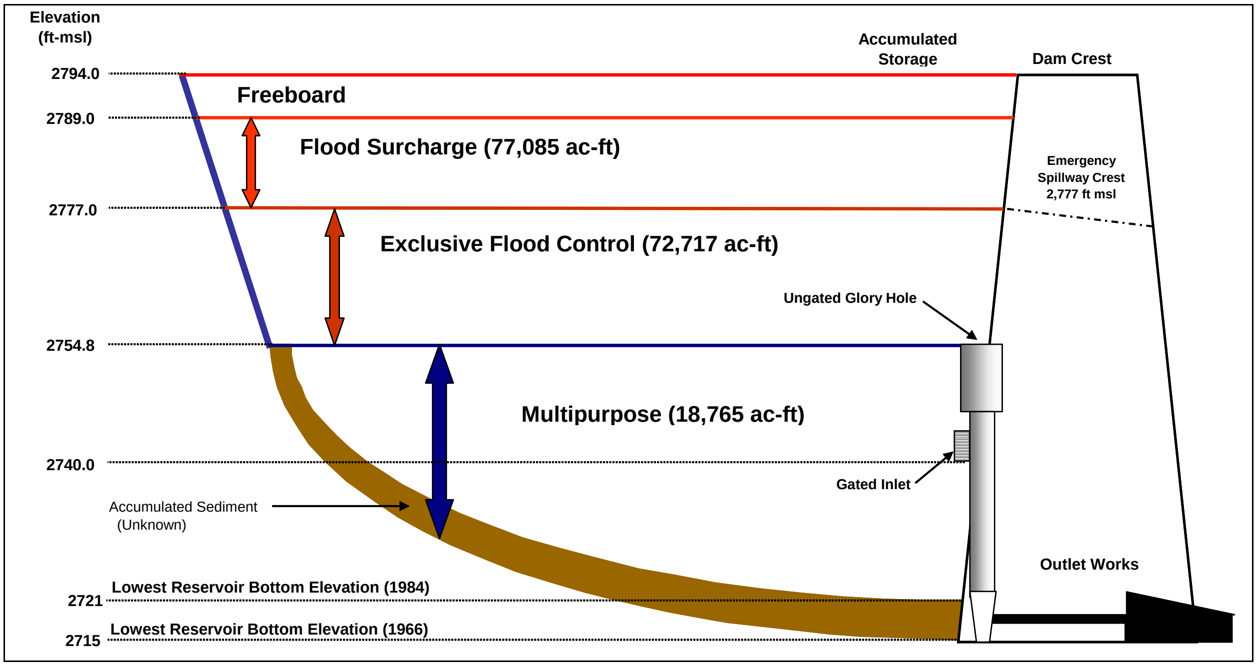

Figure 7.1. Current storage zones of Bowman-Haley Reservoir based on the 1984 survey data**.**

7.1.1.5 Historic Water Quality Concerns

Historic water quality data collection indicated that Bowman-Haley had extremely poor water quality with numerous exceedences of State water quality standards. Some authorized project purposes could not be met because of poor water quality. Due to the documented poor water quality, a public meeting was held in Bowman, North Dakota on April 8, 1985 to discuss procedures that might be employed to improve water quality in the reservoir. In 1990 the Bowman-Slope Soil Conservation District initiated a water quality improvement project focused on implementation of BMPs in the watershed.

7.1.1.6 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Bowman-Haley Reservoir since the 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Recently, the District has scaled back water quality monitoring at Bowman-Haley Reservoir, and is targeting to monitor the reservoir every 3 years. Figure 7.2 shows the location of the sites that are targeted for current water quality monitoring. During the past 10 years, the District conducted water quality monitoring at Bowman-Haley Reservoir in 2001 through 2004 and in 2010.

7.1.2 Existing Water Quality Conditions

7.1.2.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Bowman-Haley Reservoir at sites BOWLKND1, BOWLKMLN1, and BOWLKMLS1 from May through September during the 10-year period 2001 through 2010 are summarized, respectively, in Plates 255 through 257. A review of these results indicated possible water quality concerns regarding sulfate.

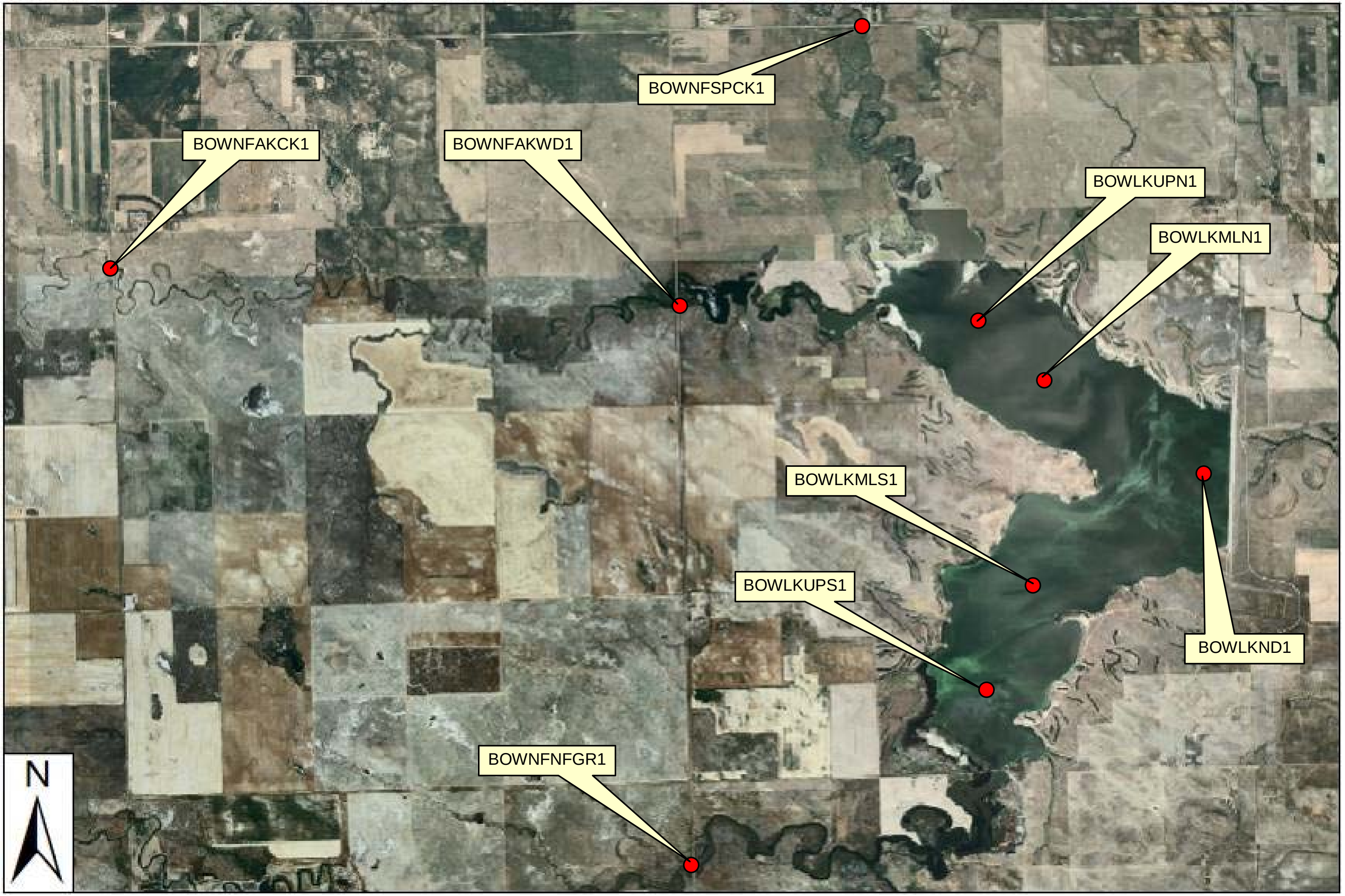

Figure 7.2. Location of sites where water quality monitoring was conducted at Bowman-Haley Reservoir during the period 2001 through 2010.

North Dakota's water quality standards define a criterion of 250 mg/l for sulfates (total as SO_4) which is applicable to Class I Streams including lakes. As such this criterion is applicable to Bowman-Haley Reservoir. The sulfate criterion was exceeded in all 13 samples collected from Bowman-Haley Reservoir for which sulfate was measured. The high sulfate levels are believed to be a natural condition attributable to the soils of the region.

7.1.2.2 Thermal Stratification

Existing summer thermal stratification of Bowman-Haley Reservoir, at the deep water area near the dam, is described by the depth-profile temperature plots measured over the past 10 years. Depth-profile temperature plots measured during the summer were compiled (Plate 258). The plotted depth-profile temperature measurements indicate that the reservoir seldom exhibits significant summer thermal stratification. Since Bowman-Haley Reservoir ices over in the winter and seemingly exhibits periodic circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

7.1.2.3 Summer Dissolved Oxygen Conditions

Existing summer dissolved oxygen conditions in Bowman-Haley Reservoir at the deep water area near the dam are described by dissolved oxygen depth-profiles measured over the past 10 years. Dissolved oxygen depth-profiles measured during the summer were compiled and plotted (Plate 259). A significant vertical gradient in summer dissolved oxygen levels rarely occurred.

7.1.2.4 Water Clarity

Figure 7.3 displays a box plot of the Secchi depth transparencies measured at the five in-reservoir monitoring sites (i.e., BOWLKND1, BOWLKMLS1, BOWLKMLN1,) during the 2001 through 2010 period (note: the monitoring sites are oriented in an upstream to downstream direction). Water clarity in the reservoir was highest in the north arm and lowest in the south arm; while the area near the dam was intermediary. An indication of the differing water clarity in the two arms of the reservoir can be seen in the 2006 aerial photo of the reservoir (Figure 7.2).

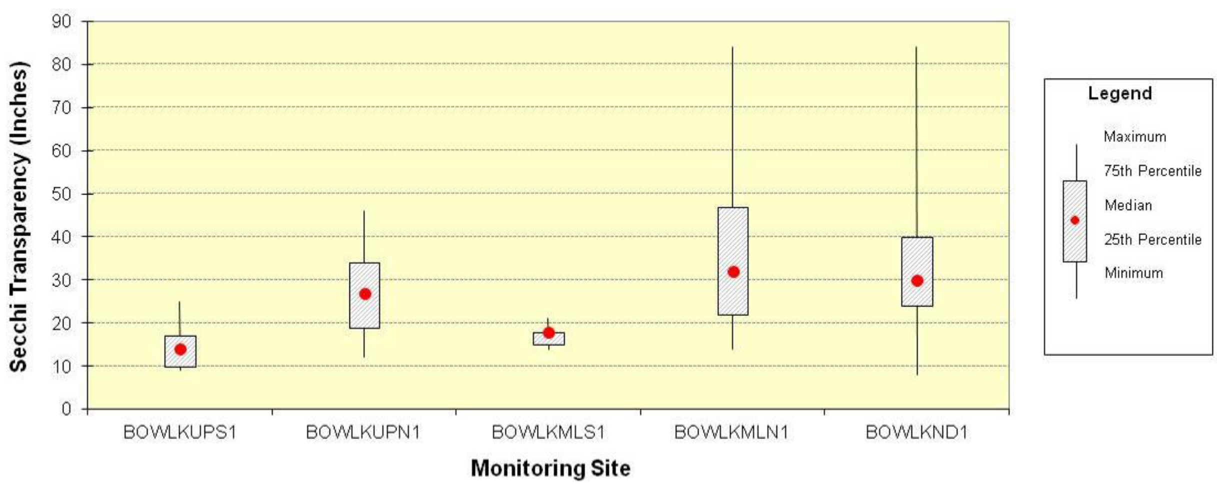

Figure 7.3. Box plot of Secchi depth transparencies measured in Bowman-Haley Reservoir during the period 2002 through 2010.

7.1.2.5 Comparison of Near-Surface and Near-Bottom Water Quality Conditions

Paired near-surface and near-bottom water quality samples collected from Bowman-Haley Reservoir during the summer were compared. Near-surface conditions were represented by samples collected within 1-meter of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site BOWLKND1 during the 10-year period 2001 through 2010. During the 10-year period a total of 17 paired samples were collected monthly during the summer. Box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature (17), dissolved oxygen (17), oxidation-reduction potential (8), pH (17), alkalinity (14), total organic carbon (9), total Kjeldahl nitrogen (14), total ammonia (11), and total phosphorus (14) (Plate 260). *[Note: the number in parentheses is the number of paired observations available for each parameter]*. A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different (α = 0.05). The sampled near-surface and near-bottom conditions were not significantly different for oxidation-reduction potential, alkalinity, total organic carbon, total Kjeldahl nitrogen, total ammonia, and total phosphorus. Parameters that were significantly lower in the near-bottom water of Bowman-Haley Reservoir during the summer included: water temperature ($p < 0.01$), dissolved oxygen ($p < 0.01$), and pH ($p < 0.005$).

7.1.2.6 Reservoir Trophic Status

Trophic State Index (TSI) values for Bowman-Haley Reservoir were calculated from monitoring data collected during the 10-year period 2001 through 2010 at the near-dam ambient monitoring site (i.e., BOWLKND1). Table 7.2 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Bowman-Haley Reservoir is in a eutrophic condition. Based on the State of North Dakota's impairment assessment methodology, the TSI values indicated that the trophic conditions of Bowman-Haley Reservoir fully support aquatic life and recreation.

Table 7.2. Summary of Trophic State Index (TSI) values calculated for Bowman-Haley Reservoir for the 10-year period of 2001 through 2010.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	21	64	64	49	83
TSI(TP)	21	62	63	52	69
TSI(Chl)	13	53	53	40	81
TSI(Avg)	25	61	60	49	70

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values.
Note: See Section 4.1.3 for discussion of TSI calculation.

7.1.3 WATER QUALITY TRENDS (1980 THROUGH 2010)

Water quality trends from 1980 to 2010 were determined for Bowman-Haley Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through September at the near-dam monitoring site (i.e., BOWLKND1). Plate 261 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, Bowman-Haley Reservoir exhibited an increasing trend in transparency, and decreasing trends in total phosphorus, and chlorophyll *a*. Over the 31-year period since 1980, Bowman-Haley Reservoir has seemingly improved from a borderline hypereutrophic to a eutrophic condition (Plate 261).

7.1.3.1.1 Existing Water Quality Conditions of Inflows to Bowman-Haley Hill Reservoir

Existing water quality conditions in the main tributary inflows to Bowman-Haley Reservoir were monitored at four sites BOWNFAKCK1, BOWNFAKWD1, BOWNFNFGR1, and BOWNFSPCK1 (Figure 7.2). Plates 262 through and 265, respectively, summarize water quality conditions that were monitored at sites BOWNFAKCK1, BOWNFAKWD1, BOWNFNFGR1, and BOWNFSPCK1 during the period 2001 through 2002 (Plates 262 through 265).

7.2 PIPESTEM RESERVOIR

7.2.1 BACKGROUND INFORMATION

7.2.1.1 Project Overview

The dam forming Pipestem Reservoir is located on Pipestem Creek, 3 miles northwest of Jamestown, North Dakota. The dam was completed in July 1973 and the reservoir reached its initial fill in May 1974. The Pipestem Reservoir watershed is 594 square miles. The watershed was largely agricultural and rangeland when the dam was built in 1974 and has remained so to the present time. The authorized project purposes of Pipestem Reservoir are flood control, recreation, fish and wildlife, and water quality.

7.2.1.2 Pipestem Dam Intake Structure

The intake at Pipestem Dam is an ungated drop inlet with a weir elevation of 1442.4 ft-msl. The intake structure has two 4 feet x 7 feet hydraulic slide service gates and two low-level gates. The two low-level gates are a 3 foot x 3 foot slide gate at invert elevation 1433.0 ft-msl, and a 3 foot diameter slide gate at invert elevation 1415.0 ft-msl. Since the top of the multipurpose pool is also the crest of the ungated weir, no specific regulation of water levels of the multipurpose pool is required. Regulation for conservation will normally be automatic in that the incoming water will flow over the weir crest. The two low-level gates allow for the release of water from the multipurpose pool. The higher outlet is designed to meet water quality and downstream requirements. The lower outlet is provided for emergency drainage of the reservoir but may also be used for other purposes.

7.2.1.3 Reservoir Storage Zones

Figure 7.4 depicts the current storage zones of Pipestem Reservoir based on the 2002 survey data and estimated sedimentation. It is estimated that 8 percent of the "as-built" volume to the top of the Multipurpose Pool has been lost to sedimentation as of 2008. The annual volume loss is estimated to be 0.23 percent.

7.2.1.4 Water Quality Standards Classifications, Section 303(d) Listings, and Fish Consumption Advisories

The State of North Dakota has designated Pipestem Reservoir as a Class 3 lake in the State's water quality standards. The beneficial uses designated for Class I streams are also applicable to all classified lakes in North Dakota. As such, the beneficial uses designated for Pipestem Reservoir are: primary contact recreation, warmwater fishery, wildlife, and agricultural water supply. Water quality is also to be suitable for municipal or domestic use after appropriate treatment. The reservoir is not directly used as a municipal or domestic water supply.

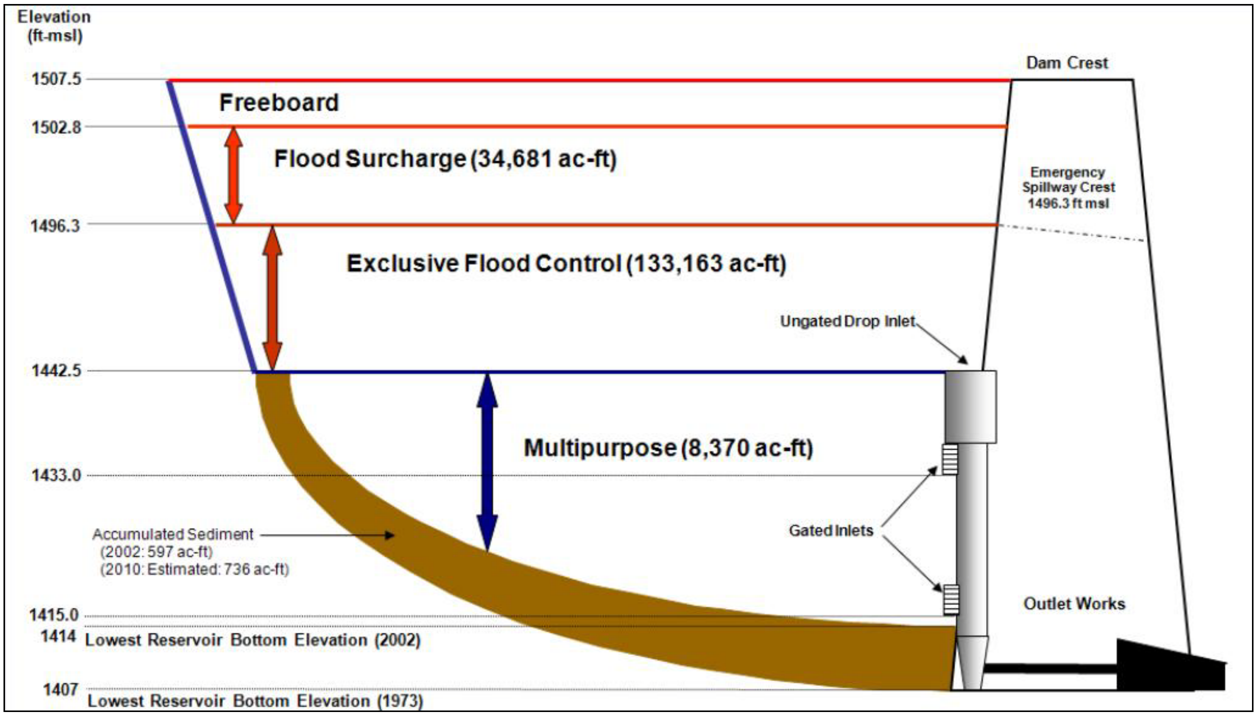

Figure 7.4. Current storage zones of Pipestem Reservoir based on the 2002 survey data and estimated sedimentation**.**

Pursuant to the Federal CWA, the State of North Dakota has listed Pipestem Reservoir on the State's 2010 Section 303(d) list (see Table 1.3). The beneficial use identified as fully supported but threatened is recreation. The impairment of the use is attributed to nutrients and eutrophication. The development of a TDML for Pipestem Reservoir has been given a high priority rating. The State of North Dakota has issued a statewide fish consumption advisory for mercury. As such, the mercury advisory applies to Pipestem Reservoir.

7.2.1.5 <u>Historic Water Quality Concerns</u>

Following the initial fill of the multipurpose pool in 1974 and prior to the spring runoff in 1975, water quality measurements indicated severe oxygen depletions existed in the reservoir under the ice cover. Further investigations confirmed that elevated levels of nitrogen, phosphorus, and organic matter occurred near the bottom of the reservoir. In an effort to improve the recreational and fish and wildlife quality of the reservoir, a sluicing operation was conducted using the lower low-level outlet to draw off the poor quality water near the reservoir bottom. The decision was made to proceed with this operation after it was determined that the impending snowmelt runoff would fill the reservoir to the multipurpose pool. The low-level releases were monitored during the operation, and it was found that the released water was rapidly oxygenated and did not cause any adverse affects downstream.

Current operations at Pipestem dam include keeping the lower low-level gate open during periods when water is flowing over the crest of the drop inlet structure in an effort to draw some water from the reservoir bottom and improve the water quality in the reservoir. It appears this may also be facilitating the passage of sediment through the dam and reducing sedimentation within the reservoir. Sediment surveys conducted by the District in 1990 and 2002 indicate that sedimentation near the dam has remained at the elevation of the low-level gate (Table 7.1 and Figure 7.4).

7.2.1.6 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Pipestem Reservoir since the late 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Recently, the District has scaled back water quality monitoring at Pipestem Reservoir, and is planning to monitor the reservoir every 3 years. Figure 7.5 shows the location of the sites that were monitored during the 10-year period 2001 through 2010. During the past 10 years, the District conducted water quality monitoring at Pipestem Reservoir in 2001 - 2004, 2007, and 2010.

7.2.2 EXISTING WATER QUALITY CONDITIONS

7.2.2.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Pipestem Reservoir at sites PIPLKND1, PIPLKML1, and PIPLKUP1 from May through September during the period 2001 through 2010 are summarized, respectively, in Plates 266 through 268. A review of these results indicated possible water quality concerns regarding sulfates.

North Dakota's water quality standards define a criterion of 250 mg/l for sulfates (total as SO_4) which is applicable to Class I Streams including lakes. As such this criterion is applicable to Pipestem Reservoir. The sulfate criterion was exceeded throughout Pipestem Reservoir (Plates 266 to 268). The high sulfate levels are believed to be a natural condition attributable to the soils of the region.

7.2.2.2 Thermal Stratification

7.2.2.2.1 Longitudinal Temperature Contour Plots

Late-spring and summer thermal conditions of Pipestem Reservoir measured during 2007 and 2010 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plates 269 and 270 provide longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites PIPLKND1 and PIPLKML1 in 2007 and PIPLKND1, PIPLKML1, and PIPLKUP1 in 2010. These temperature plots indicate that Pipestem Reservoir exhibited some thermal stratification in both years. The maximum difference monitored between the surface and bottom water temperatures was 8°C in August of 2010 (Plate 270).

7.2.2.2.2 Near-Dam Temperature Depth-Profile Plots

Existing summer thermal stratification of Pipestem Reservoir, at the deep water area near the dam, measured over the 10-year period 2001 through 2010 is depicted by depth-profile temperature plots (Plate 271). The depth-profile temperature plots indicate that the reservoir has regularly exhibited significant summer thermal stratification over the past 10 years. Since Pipestem Reservoir ices over in the winter and seemingly exhibits periodic circulation during the summer, it appears to fit the definition of a discontinuous cold polymictic lake (Wetzel, 2001).

Figure 7.5. Location of sites where water quality monitoring was conducted at Pipestem Reservoir during the period 2001 through 2010.

7.2.2.3 Summer Dissolved Oxygen Conditions

7.2.2.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Pipestem Reservoir based on depth-profile measurements taken during 2007 at sites PIPLKND1 and PIPLKML1, and sites PIPLKND1, PIPLKML1, and PIPLKUP1 in 2010. Plates 272 and 273 provide longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September in 2007 and 2010. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored along the reservoir bottom near the dam in both years (Plates 272 and 273).

7.2.2.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

Existing summer dissolved oxygen conditions in Pipestem Reservoir are described by the dissolved oxygen depth-profiles measured near the dam over the 10-year period 2001 through 2010. Summer dissolved oxygen depth-profiles were compiled and plotted for the 10 years (Plate 274). On most occasions there was a significant vertical gradient in summer dissolved oxygen levels. Hypoxic to anoxic conditions were monitored near reservoir bottom on several occasions. Super saturation of dissolved oxygen was monitored in August of 2010 (Plates 273 and 274) and attributed to high rates of algal photosynthesis during the day. Although Pipestem Reservoir appears to be polymictic based on thermal stratification, there seems to be enough inhibition to mixing to allow degraded dissolved oxygen conditions to develop near the reservoir bottom.

7.2.2.3.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of Pipestem Reservoir with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2010 and the District's Area-Capacity Tables (1990 Survey) for the reservoir. The constructed contour plots were reviewed to identify the "worst-case" dissolved oxygen condition. The "worst-case" condition was taken to be the contour plot with the highest elevations of the 5 mg/l and 2.5 mg/l dissolved oxygen isopleths. The August 9, 2010 contour plot indicates a pool elevation of 1444.0 ft-msl, a 5 mg/l dissolved oxygen isopleth elevation of about 1435.0 ft msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1434 ft-msl (Plate 273). The District's Area-Capacity Tables give storage capacities of 10,258 ac-ft for elevation 1444.0 ft-msl, 3,840 ac-ft for elevation 1435.0 ft-msl, and 3,346 ac-ft for elevation 1434.0 ft-msl. On August 9, 2010 it is estimated that 37 percent of the volume of Pipestem Reservoir was less than the 5 mg/l dissolved oxygen criterion for the protection of aquatic life, and 33 percent of the reservoir volume was hypoxic.

7.2.2.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in Pipestem Reservoir indicated hypoxic conditions were present during the summers of 2007 and 2010, longitudinal contour and depth-profile plots were constructed for ORP and pH. Near-surface and near-bottom water quality samples collected when hypoxia was present were also compared.

7.2.2.4.1 Oxidation-Reduction Potential

Plates 275 and 276 provide longitudinal ORP contour plots based on depth-profile measurements taken in 2007 and 2010. The ORP values indicated reduced conditions occurred near the reservoir bottom when hypoxic conditions were monitored (Plates 275 and 276). Plate 277 plots depth profiles for ORP measured during the summer over the 7 year period 2003 through 2010 in the deep water area of Pipestem

Reservoir near the dam. The ORP depth profiles indicate that appreciable reduced conditions occasionally occurred in Pipestem Reservoir during the summer (Plate 277).

7.2.2.4.2 pH

Longitudinal contour plots for pH conditions measured in 2007 and 2010 are provided in Plates 278 and 279. Plate 280 plots depth profiles for pH measured during the summer over the 10-year period 2001 through 2010 in the deep water area of Pipestem Reservoir near the dam. An appreciable vertical gradient in pH occasionally occurred in the reservoir during the summer (Plates 278 and 279). It appears occasional reduced conditions in the deeper water of Pipestem Reservoir seemingly lead to lower pH levels near the reservoir bottom. The lowest measured pH levels near the reservoir bottom were 6.9; this is just below the lower pH criterion of 7.0 for the protection of aquatic life.

7.2.2.4.3 Comparison of Near-Surface and Near-Bottom Water Quality Conditions

Paired near-surface and near-bottom water quality samples collected from Pipestem Reservoir during the summer when hypoxia was present were compared. Near-surface conditions were represented by samples collected within 1-meter of the reservoir surface, and near-bottom conditions were represented by samples collected within 1-meter of the reservoir bottom. The compared samples were collected at the near-dam site PIPLKND1 during the 10-year period 2001 through 2010. During the 10-year period a total of 30 paired samples were collected monthly from May through September. Of the 30 paired samples collected, 13 (43%) had near-bottom samples with less than 2.5 mg/l dissolved oxygen. For the paired samples with hypoxic near-bottom conditions, box plots were constructed to display the distribution of measured water quality conditions for the following parameters: water temperature (13), dissolved oxygen (13), oxidation-reduction potential (7), pH (12), alkalinity (10), total ammonia (8), nitrate-nitrate nitrogen (10), total phosphorus (10), and orthophosphorus (10) (Plate 281) *[Note: the number in parentheses is the number of paired observations available for each parameter]*. A paired two-tailed t-test was used to determine if the sampled near-surface and near-bottom conditions for the paired samples were significantly different ($\alpha = 0.05$). The sampled near-surface and near-bottom conditions were not significantly different for oxidation-reduction potential, nitrate-nitrite nitrogen, or alkalinity. Parameters that were significantly lower in the near-bottom water of Pipestem Reservoir when hypoxia was present included: water temperature ($p < 0.0001$), dissolved oxygen ($p < 0.0001$) and pH ($p < 0.0001$). Parameters that were significantly higher in the near-bottom water of Pipestem Reservoir when hypoxia was present included: total ammonia ($p <0.05$), total phosphorus ($p <0.05$), and orthophosphorus ($p<0.01$).

7.2.2.5 <u>Water Clarity</u>

7.2.2.5.1 Secchi Transparency

Figure 7.6 displays a box plot of the Secchi depth transparencies measured at the three in-reservoir monitoring sites (i.e., PIPLKUP1, PIPLKML1, and PIPLKND1) during the 10-year period 2001 through 2010 (note: the monitoring sites are oriented in an upstream to downstream direction). Water clarity in the reservoir was noticeably higher near the dam as compared to sites farther upstream (Figure

7.6)

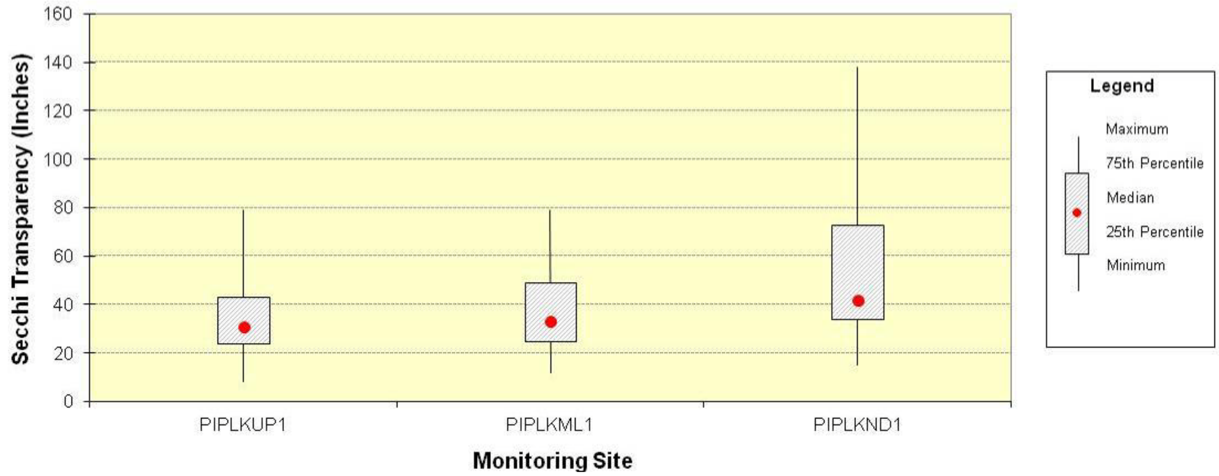

Figure 7.6. Box plot of Secchi depth transparencies measured in Pipestem Reservoir during the period 2001 through 2010.

7.2.2.5.2 Turbidity

Turbidity contour plots were constructed along the length of Pipestem Reservoir based on depth-profile measurements taken during 2007 and 2010. Plates 282 and 283 provide longitudinal turbidity contour plots based on depth-profile measurements taken from May through September at sites PIPLKND1, PIPLKML1, and PIPLKUP1. Pipestem Reservoir occasionally exhibited longitudinal and depth variability in turbidity.

7.2.2.6 <u>Reservoir Trophic Status</u>

Trophic State Index (TSI) values for Pipestem Reservoir were calculated from monitoring data collected during the 10-year period 2001 through 2010 at the near-dam ambient monitoring site (i.e., PIPLKND1). Table 7.3 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Pipestem Reservoir is in a eutrophic to hypereutrophic condition. Based on the State of North Dakota’s impairment assessment criteria, the TSI values indicate that the aquatic life and recreation uses of Pipestem Reservoir are likely impaired.

Table 7.3. Summary of Trophic State Index (TSI) values calculated for Pipestem Reservoir for the 10-year period of 2001 through 2010.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	30	57	58	42	74
TSI(TP)	29	77	78	66	85
TSI(Chl)	24	64	63	46	87
TSI(Avg)	30	66	66	55	80

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values.

Note: See Section 4.1.3 for discussion of TSI calculation.

7.2.3 Water Quality Trends (1980 through 2010)

Water quality trends from 1980 to 2010 were determined for Pipestem Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through September at the near-dam monitoring site (i.e., PIPLKND1). Plate 284 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, Pipestem Reservoir exhibited an increasing trend in total phosphorus and little to no trend in transparency and chlorophyll *a*. Over the 25-year period since 1980, Pipestem Reservoir has remained in a eutrophic to hypereutrophic condition (Plate 284).

7.2.4 Existing Water Quality Conditions of Inflows to Pipestem Reservoir

Existing water quality conditions in the main tributary inflow to Pipestem Reservoir were monitored on Pipestem Creek at site PIPNF1 (Figure 7.5). Plate 285 summarizes water quality conditions that were monitored at site PIPNF1 during 2001 (Plate 285).

SOUTH DAKOTA TRIBUTARY PROJECTS

Two District Tributary Projects are located in South Dakota: Cold Brook and Cottonwood Springs. Cold Brook and Cottonwood Springs reservoirs are located in southwest South Dakota in the Black Hills area near Hot Springs, South Dakota (Figure 1.1). Table 8.1 gives selected engineering data for the Cold Brook and Cottonwood Springs Projects.

7.3 COLD BROOK RESERVOIR

7.3.1 BACKGROUND INFORMATION

7.3.1.1 Project Overview

The dam forming Cold Brook Reservoir is located on Cold Brook Creek, approximately 1-mile upstream from its confluence with the Fall River, and 2 miles north of Hot Springs, South Dakota. The dam was completed in September 1952 and the reservoir reached its initial fill in June 1963. The Cold Brook Reservoir watershed is 70.5 square miles. The watershed was largely rangeland and forested when the dam was built in 1952 and has remained so to the present time. The authorized project purposes of Cold Brook Reservoir are flood control, recreation, fish and wildlife, and water quality.

7.3.1.2 Cold Brook Dam Intake Structure

The intake structure at Cold Brook Dam is a circular (6.67 ft inside diameter) freestanding tower of reinforced concrete having an ungated bell-mouthed entrance. Supported on four buttress-type spread footings, the tower stands in the deepest part of the reservoir, about 70 feet upstream from the toe of the dam. The crest of the bell-mouthed entrance is at elevation 3600.0 ft-msl. Four port openings, each 1.2 feet high by 3.0 feet wide, are spaced evenly around the periphery of the vertical tower at elevation 3585.0 ft-msl, which is the upper limit of the conservation pool. Lowering of the surface of the conservation pool to a minimum elevation of 3548 ft-msl is accomplished by manual control of three 12-inch gate values located in the footings of the tower which discharge through the openings into the conduit.

Three 8-inch diameter inlets were originally provided at elevations 3580.0, 3560.0, and 3548.0 ft-msl as intakes for the Larvie Lake supply line. The inlets were modified in 1978 to enhance the water supply to Larvie Lake. The lowest inlet (i.e., elevation 3548.0 ft-msl) was located on the bottom of the reservoir and was abandoned due to the excessive amount of silts that were captured by the inlet and passed to Larvie Lake. Inlet covers were placed on both faces of the inlet at this elevation to seal the opening. Similar inlet covers were placed on the left side of the structure legs over the inlets at 3580.0 and 3560.0 ft-msl. Slide gates were placed over the right side of the inlet openings. A gate stem was extended from the gates to the grating deck where a gate lift mechanism was constructed to the structure leg.

7.3.1.3 Reservoir Storage Zones

Figure 8.1 depicts the current storage zones of Cold Brook Reservoir based on 1972 computations. The District has not conducted sediment surveys at Cold Brook Reservoir; therefore, the current amount of sedimentation has not been estimated and is unknown.

Table 8.1. Summary of selected engineering data for the Cold Brook and Cottonwood Springs Projects.

	Cold Brook Reservoir		Cottonwood Springs Reservoir	
General				
Dammed Stream	Cold Brook Creek		Cottonwood Springs Creek	
Drainage Area	70.5 sq. mi.		26 sq. mi.	
Reservoir Length[(1)]	1.2 miles		0.6 miles	
Multipurpose Pool Elevation (Top)	3585.0 ft-msl		3875.0 ft-msl	
Date of Dam Closure	September 1952		May 1969	
Date of Initial Fill[(2)]	June 1963		Not yet reached	
"As-Built" Conditions[(3)]	(1972 Computations)		(1971 Computations)	
Lowest Reservoir Bottom Elevation	3539 ft-msl		3839 ft-msl	
Surface Area at top of Multipurpose Pool	36 ac		44 ac	
Capacity to top of Multipurpose Pool	520 ac-ft		655	
Mean Depth at top of Multipurpose Pool[(4)]	14.4 ft		14.9 ft	
Latest Surveyed Conditions	(1972 Computations)		(1971 Computations)	
Lowest Reservoir Bottom Elevation	3539 ft-msl		3839 ft-msl	
Surface Area at top of Multipurpose Pool	36 ac		44 ac	
Capacity of Multipurpose Pool	520 ac-ft		655	
Mean Depth at top of Multipurpose Pool[(4)]	14.4 ft		14.9 ft	
Sediment Deposition in Multipurpose Pool				
Historic Sediment Deposition[(5)]	Unknown[(9)]		Unknown[(9)]	
Annual Sedimentation Rate[(6)]	Unknown[(9)]		Unknown[(9)]	
Current Estimated Sediment Deposition[(7)]	Unknown[(9)]		Unknown[(9)]	
Current capacity of Multipurpose Pool[(8)]	Unknown[(9)]		Unknown[(9)]	
Percent of "As-Built" Multipurpose Pool capacity lost to current estimated sediment deposition	Unknown[(9)]		Unknown[(9)]	
Operational Details – Historic	(1964 – 2010)		(1973 – 2010)	
Maximum Recorded Pool Elevation	3585.7 ft-msl	28-Jun-10	3872.7 ft-msl	23-Mar-00
Minimum Recorded Pool Elevation	3565.9 ft-msl	1-Aug-53	3832.4 ft-msl	30-Sep-89
Maximum Recorded Daily Inflow	74 cfs	14-Jul-62	52 cfs	20-Aug-93
Maximum Recorded Daily Outflow	19 cfs	4-Jul-99	No Outflow	
Average Annual Pool Elevation	3580.7 ft-msl		3847.8 ft-msl	
Average Annual Inflow	710 ac-ft		36 ac-ft	
Average Annual Outflow	610 ac-ft		No Outflow	
Estimated Retention Time[(10)]	0.85 Years		-----	
Operational Details – Current[(11)]				
Maximum Recorded Pool Elevation	3585.7 ft-msl	28-Jun-10	3844.7 ft-msl	31-Jul-10
Minimum Recorded Pool Elevation	3581.3 ft-msl	5-May-10	3837.0 ft-msl	27-Apr-10
Maximum Recorded Daily Inflow	13 cfs	22-Jun-10	< 1 cfs	
Maximum Recorded Daily Outflow	13 cfs	28-Jun-10	No Outflow	
Total Inflow (% of Normal)	875 ac-ft	(129%)	22 ac-ft	(68%)
Total Outflow (% of Normal)	792 ac-ft	(137%)	No Outflow	
Outlet Works				
Ungated Outlets	Drop Inlet	3585.0 ft-msl	Drop Inlet 3875.0 ft-msl	
Gated Outlets (Mid-depth)	1) 8" Dia. Slide Gate 1) 8" Dia. Slide Gate	3580.0 ft-msl 3560.0 ft-msl	1) 3'x 3' Slide Gate	3868.0 ft-msl
Gated Outlets (Low-level)	3) 12" Gate Valves	3548.0 ft-msl		

(1) Reservoir length at top of conservation pool.
(2) First occurrence of reservoir pool elevation to top of multipurpose pool elevation.
(3) "As-Built" conditions taken to be the conditions present when the reservoir was first surveyed.
(4) Mean Depth = Volume ÷ Surface Area.
(5) Difference in reservoir storage capacity to top of Multipurpose Pool between "as-built" and latest survey.
(6) Annualized rate based on historic accumulated sediment.
(7) Current accumulated sediment estimated from historic annual sedimentation rate.
(8) Current capacity of Multipurpose Pool = "As-Built" Multipurpose Pool capacity - Estimated Current Sedimentation.
(9) Unable to calculate accumulated sediment and sediment deposition rates because no bathymetric surveys conducted on either reservoir.
(10) Estimated Retention Time = Multipurpose Pool Volume ÷ Average Annual Outflow.
(11) Current operational details are for the water year 1-Oct-2009 through 30-Sep-2010.

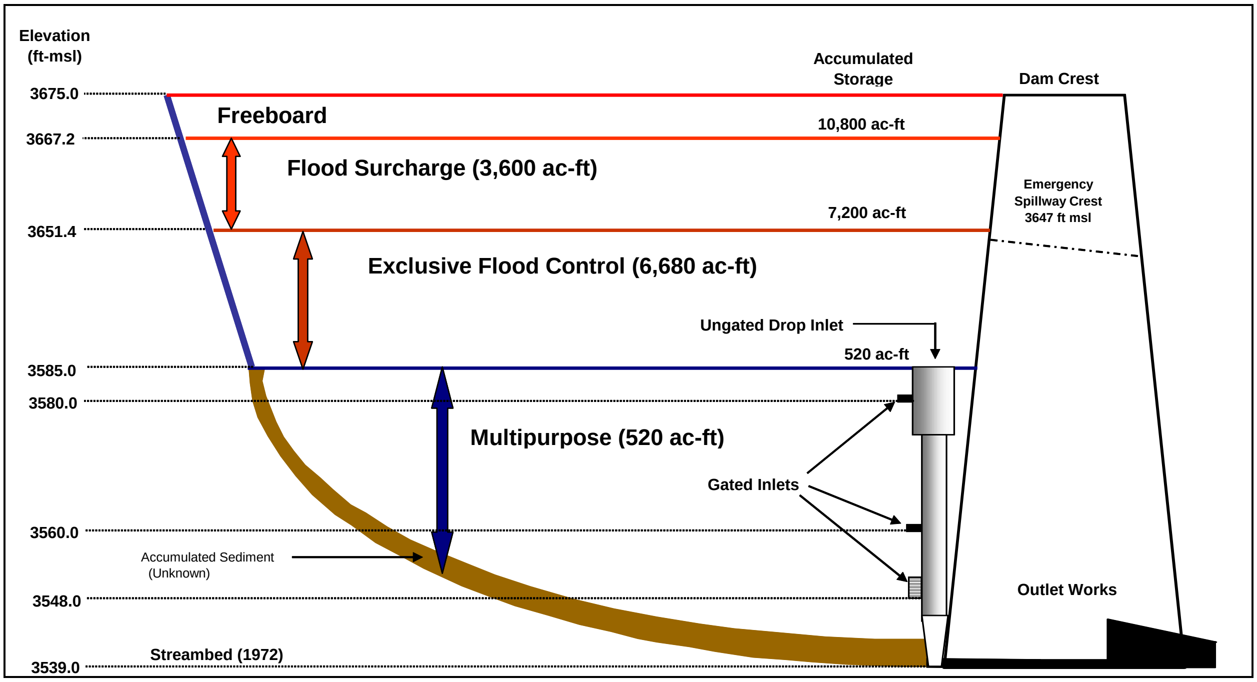

Figure 8.1. Current storage zones of Cold Brook Reservoir based on the 1972 computations**.**

7.3.1.4 Water Quality Standards Classifications, Section 303(d) Listings, and Fish Consumption Advisories

As identified in the State of South Dakota's water quality standards, the following beneficial uses are designated for Cold Brook Reservoir: recreation (immersion and limited contact), coldwater permanent fish life propagation, fish and wildlife propagation, stock watering, and domestic water supply. The reservoir is not directly used as a municipal or domestic water supply. Pursuant to the Federal CWA, the State of South Dakota has listed Cold Brook Reservoir on the State's 2010 Section 303(d) list (see Table 1.3). The beneficial use identified as impaired is coldwater permanent fish life. The impairment of the use is attributed to natural warming of water temperatures and high pH. The State of South Dakota has not issued a fish consumption advisory for the reservoir.

7.3.1.5 Ambient Water Quality Monitoring

The District has monitored water quality conditions at Cold Brook Reservoir since the 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Recently, the District has scaled back water quality monitoring at Cold Brook Reservoir, and is targeting to monitor the reservoir every 3 years. Cold Brook Reservoir was last monitored in 2008. Figure 8.2 shows the location of the sites that monitored during the 10-year period 2001 through 2010. During that period water quality monitoring was conduct in the years 2001 - 2003, 2005, and 2008.

Figure 8.2. Location of sites where water quality monitoring was conducted at Cold Brook Reservoir during the period 2001 through 2010.

7.3.2 EXISTING WATER QUALITY CONDITIONS

7.3.2.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Cold Brook Reservoir at sites CODLKND1, CODLKML1, and CODLKUP1 from May through September during the 10-year period 2001 through 2010 are summarized, respectively, in Plates 286 through 288. A review of these results indicated possible water quality concerns regarding water temperature, dissolved oxygen, and arsenic.

The temperature criterion of 65° F (18.3°C) for the protection of coldwater permanent fish life propagation was exceeded by over 65 percent of measurements taken in Cold Brook Reservoir. It is noted that if the reservoir were classified for the protection of coldwater marginal fish life propagation the criterion of 75°F (23.9°C) would have been exceeded by only 20% of the measurements. The temperature criterion of 80°F (26.6°C) for the protection of warmwater permanent fish life propagation would not have been exceeded at any time. Ambient water temperatures in Cold Brook Reservoir do not appear to be cold enough to support coldwater permanent fish life propagation as defined by State water quality standards criteria. Consideration should be given to reclassify Cold Brook Reservoir for either coldwater marginal fish life propagation or warmwater permanent fish life propagation use based on a use attainability assessment of "natural conditions" regarding ambient water temperatures.

Dissolved oxygen criteria were exceeded by less than 10 percent of the dissolved oxygen measurements taken in Cold Brook Reservoir. The lower dissolved oxygen concentrations occurred in the deeper part of the measured depth profile and were associated with a temperature gradient. The lower dissolved oxygen concentrations in the deeper water of Cold Brook Reservoir may be a concern if a coldwater fishery is to be supported. Water temperatures appear marginal in Cold Brook Reservoir for supporting a coldwater fishery, and the colder water that occurs in the reservoir during the summer is in the deeper portions where the lower dissolved oxygen levels occur.

The arsenic human health criterion for surface waters was exceeded by all of the arsenic measurements sampled in Cold Brook Reservoir. The arsenic criterion for human health protection is extremely low (i.e., 0.018 ug/l), and the measured arsenic levels were well below the criteria for the protection of aquatic life.

7.3.2.2 Thermal Stratification

7.3.2.2.1 Longitudinal Temperature Contour Plots

Late-spring and summer thermal conditions of Cold Brook Reservoir measured during 2008 are depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 289 provides longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites CODLKND1, CODLKML1, and CODLKUP1 in 2008. These temperature plots indicate that Cold Brook Reservoir exhibited some thermal stratification during 2008. The maximum difference monitored between the surface and bottom water temperatures during 2008 was 6°C in June and July (Plate 289).

7.3.2.2.2 Near-Dam Temperature Depth-Profile Plots

Existing summer thermal stratification of Cold Brook Reservoir, at the deep water area near the dam, measured over the 10-year period 2001 through 2010 is depicted by depth-profile temperature plots (Plate 290). The depth-profile temperature plots indicate that the reservoir regularly exhibited significant

summer thermal stratification over the past 10 years. It appears that the deepwater area near the dam may remain stratified through the middle of the summer. Since Cold Brook Reservoir ices over in the winter and seemingly exhibits extended stratification during the summer, it appears to fit the definition of a dimictic lake (Wetzel, 2001).

7.3.2.3 Summer Dissolved Oxygen Conditions

7.3.2.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Cold Brook Reservoir based on depth-profile measurements taken during 2008 at sites CODLKND1, CODLKML1, and CODLKUP1. Plate 291 provides longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September in 2008. Hypoxic conditions (i.e., < 2.5 mg/l dissolved oxygen) were monitored along the reservoir bottom near the dam in July (Plate 291).

7.3.2.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

Existing summer dissolved oxygen conditions in Cold Brook Reservoir are described by the dissolved oxygen depth-profiles measured near the dam over the 10-year period 2001 through 2010. Summer dissolved oxygen depth-profiles were compiled and plotted for the 10 years (Plate 292). On several occasions there were significant vertical gradients in summer dissolved oxygen levels. Hypoxic conditions were monitored near reservoir bottom on a few occasions (Plate 292). There seems to be enough “sediment” oxygen demand and inhibition to mixing to allow degraded dissolved oxygen conditions to develop near the reservoir bottom.

7.3.2.3.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of Cold Brook Reservoir with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2008 and the District’s current Area-Capacity Tables (1972 Computations) for the reservoir. The constructed contour plots were reviewed to identify the “worst-case” dissolved oxygen condition. The “worst-case” condition was taken to be the contour plot with the highest elevations of the 6 mg/l and 2.5 mg/l dissolved oxygen isopleths. The July 29, 2008 contour plot indicates a pool elevation of 3582.5 ft-msl, a 6 mg/l dissolved oxygen isopleth elevation of about 3553.0 ft-msl, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 3550 ft-msl (Plate 285). The District’s Area-Capacity Tables give storage capacities of 423 ac-ft for elevation 3582.5 ft-msl, 46.0 ac-ft for elevation 3553.0 ft-msl, and 34 ac-ft for elevation 3550.0 ft-msl. On July 29, 2008 it is estimated that 11 percent of the volume of Cold Brook Reservoir was less than the 6 mg/l dissolved oxygen criterion for the protection of aquatic life, and 8 percent of the reservoir volume was hypoxic.

7.3.2.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in Cold Brook Reservoir indicated hypoxic conditions were present during the summer of 2008, longitudinal contour and depth-profile plots were constructed for ORP and pH. The number of paired samples collected when hypoxia was present was insufficient to statistically compare near-surface and near-bottom water quality conditions.

7.3.2.4.1 Oxidation-Reduction Potential

Plate 293 provides longitudinal ORP contour plots based on depth-profile measurements taken in 2008. The ORP values indicated “slightly” reduced conditions were monitored near the reservoir bottom in a small area near the dam on July 29 (Plate 293). Plate 294 plots depth profiles for ORP measured

during the summer over the 8-year period 2003 through 2010 in the deepwater area of Cold Brook Reservoir near the dam (Plate 294). The ORP depth profiles indicate that slightly reduced conditions occasionally occurred near the bottom of Cold Brook Reservoir during the summer.

7.3.2.4.2 pH

Longitudinal contour plots for pH conditions measured in 2008 are provided in Plate 295. Plate 296 plots depth profiles for pH measured during the summer over the 10-year period 2001 through 2010 in the deepwater area of Cold Brook Reservoir near the dam. An appreciable vertical gradient in pH occasionally occurred in the reservoir during the summer (Plates 295 and 296). It appears occasional reduced conditions in the deeper water of Cold Brook Reservoir seemingly lead to in lower pH levels near the reservoir bottom. The lowest measured pH levels near the reservoir bottom were above the lower pH criterion of 7.0 for the protection of aquatic life.

7.3.2.5 Water Clarity

Figure 8.3 displays a box plot of the Secchi depth transparencies measured at the three in-reservoir monitoring sites (i.e., CODLKND1, CODLKML1, CODLKUP1) during 2008 (note: the monitoring sites are oriented in an upstream to downstream direction). Water clarity measured at the three sites was very high and seemingly increased in a downstream direction (Figure 8.3).

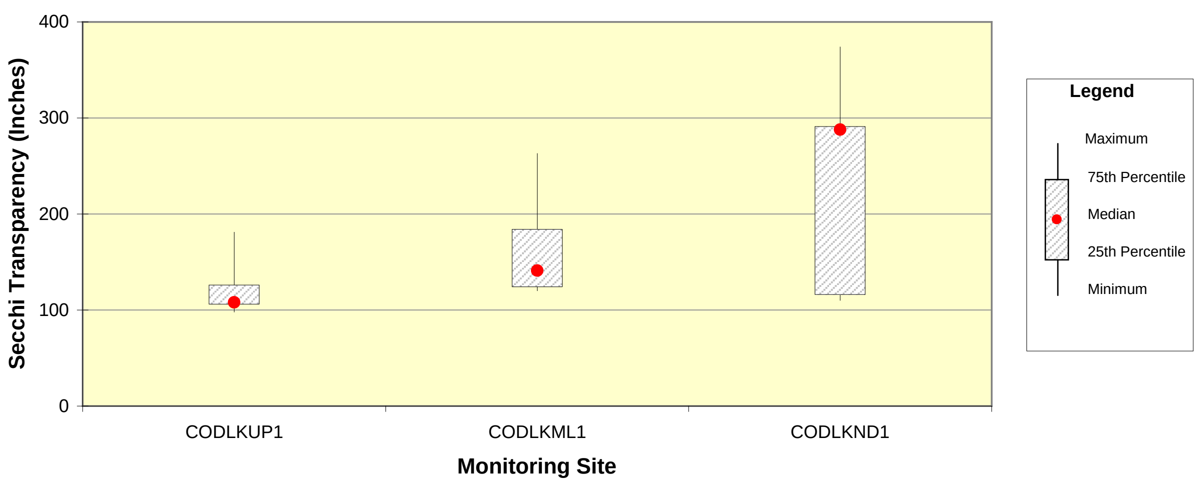

Figure 8.3. Box plot of Secchi depth transparencies measured in Cold Brook Reservoir during 2008.

7.3.2.6 Reservoir Trophic State

Trophic State Index (TSI) values for Cold Brook Reservoir were calculated from monitoring data collected during the period 2001 through 2010 at the near-dam ambient monitoring site (i.e., CODLKND1). Table 8.2 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Cold Brook Reservoir is in a mesotrophic condition.

Table 8.2. Summary of Trophic State Index (TSI) values calculated for Cold Brook Reservoir for the 10-year period of 2001 through 2010.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	15	35	35	27	45
TSI(TP)	13	49	48	41	63
TSI(Chl)	8	47	46	40	59
TSI(Avg)	15	41	43	27	50

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values.

Note: See Section 4.1.3 for discussion of TSI calculation.

7.3.3 WATER QUALITY TRENDS (1980 THROUGH 2010)

Water quality trends from 1980 to 2010 were determined for Cold Brook Reservoir for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through October at the near-dam monitoring site (i.e., CODLKND1). Plate 297 displays a scatter-plot of the collected data for the four parameters and a linear regression line. For the assessment period, Cold Brook Reservoir exhibited slightly increasing trends in transparency and total phosphorus, and a seemingly decreasing trend in chlorophyll *a*. Over the 31-year period since 1980, Cold Brook Reservoir has remained in a mesotrophic condition (Plate 297).

7.4 COTTONWOOD SPRINGS RESERVOIR

7.4.1 BACKGROUND INFORMATION

7.4.1.1 Project Overview

The dam forming Cottonwood Springs Reservoir is located on Cottonwood Springs Creek, approximately 5 miles west of Hot Springs, South Dakota. The dam was completed in May 1969 and the reservoir has not reached an initial fill. The Cottonwood Springs Reservoir watershed is 26 square miles. The watershed was largely rangeland and forested when the dam was built in 1952 and has remained so to the present time. The authorized project purposes of Cottonwood Springs Reservoir are flood control, recreation, fish and wildlife, and water quality.

7.4.1.2 Cottonwood Springs Dam Intake Structure

The intake at Cottonwood Springs Dam is a drop inlet structure consisting of a single reinforced concrete box shaft. Its inside dimensions are 4 feet by 8 feet. The structure was designed and constructed so that normal and flood period pool regulation is automatic. The intake structure has two ungated openings, each 42” x 96”, with a weir crest elevation of 3875.0 ft-msl. The weir crest elevation of 3875.0 ft-msl is the water surface elevation of the multipurpose pool. A 36” x 36” gated opening with a crest elevation of 3868.0 ft-msl was constructed into the upstream face of the intake structure. The gated outlet may be used to release water for downstream needs.

7.4.1.3 Reservoir Storage Zones

Figure 8.4 depicts the current storage zones of Cottonwood Springs Reservoir based on the 1971 "as-built" conditions. The District has not conducted sediment surveys at Cottonwood Springs Reservoir; therefore, the current amount of sedimentation has not been estimated and is unknown.

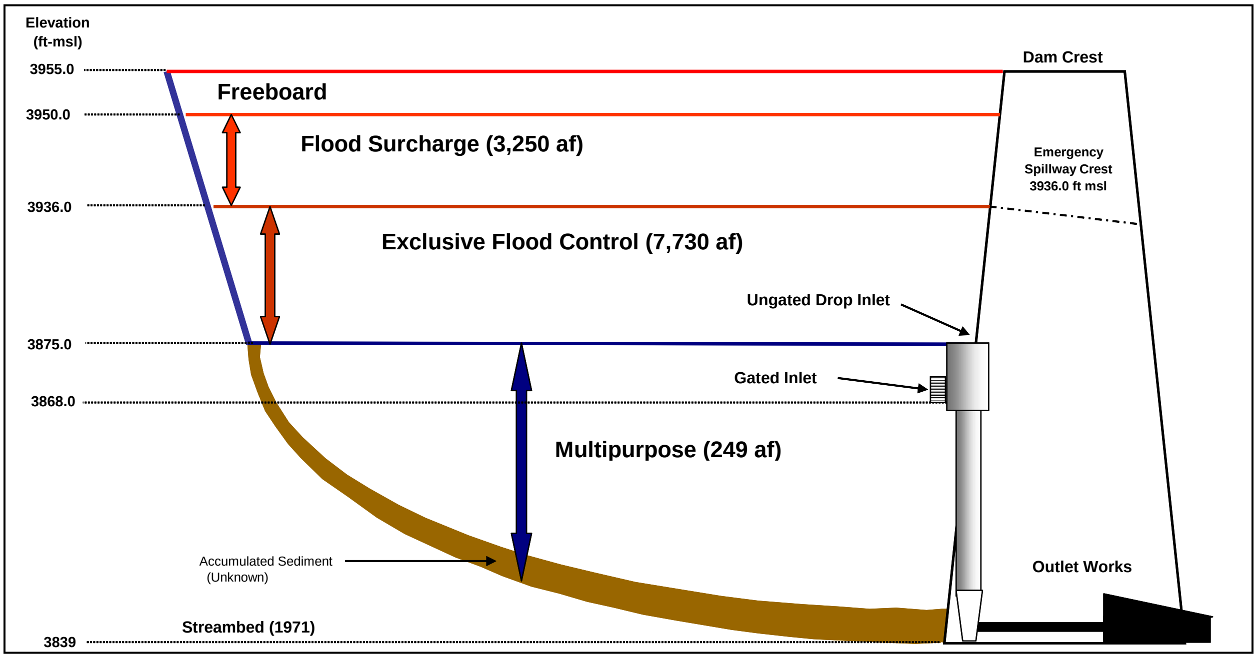

Figure 8.4. Current storage zones of Cottonwood Springs Reservoir based on the 1971 "as-built" conditions**.**

7.4.1.4 Water Quality Standards Classifications, Section 303(d) Listings, and Fish Consumption Advisories

As identified in the State of South Dakota's water quality standards, the following beneficial uses are designated for Cottonwood Springs Reservoir: recreation (immersion and limited contact), warmwater permanent fish life propagation, fish and wildlife propagation, stock watering, and domestic water supply. The reservoir is not directly used as a municipal or domestic water supply. Pursuant to the Federal CWA, the State of South Dakota has not listed Cottonwood Springs Reservoir on the State's 2010 Section 303(d) list. The State of South Dakota also has not issued a fish consumption advisory for the reservoir.

7.4.1.5 Ambient Water Quality Monitoring

The District has irregularly monitored water quality conditions at Cottonwood Reservoir since the 1970's. Water quality monitoring locations have included sites on the reservoir and on the inflow and outflow of the reservoir. Recently, the District has scaled back water quality monitoring at Cottonwood Springs Reservoir, and is targeting to monitor the reservoir every 3 years. Monitoring was scheduled for 2005 and 2008, but was not conducted because low water conditions restricted access. On September 30, 2008, the pool elevation of the reservoir was 3840.3. Based on the District's Area Capacity Tables (1971) for the reservoir this equates to a surface area of 1.6 acres and storage of 1.64 ac-ft. Figure 8.5 shows the location of the sites where water quality monitoring has occurred. Since 2001, the District conducted water quality monitoring at Cottonwood Springs Reservoir during 2001 and 2002.

Figure 8.5. Location of sites where water quality monitoring was conducted at Cottonwood Springs Reservoir during 2001 and 2002.

7.4.2 EXISTING WATER QUALITY CONDITIONS

7.4.2.1.1 Statistical Summary and Comparison to Numeric Water Quality Standards Criteria

Water quality conditions that were monitored in Cottonwood Springs Reservoir at sites COTLKND1 and COTLKML1 from May through September during the 2-year period 2001 and 2002 are summarized, respectively, in Plates 298 and 299. A review of these results indicated possible water quality concerns regarding dissolved oxygen (Plates 298 and 299).

Dissolved oxygen criteria were exceeded by about 10 percent of the dissolved oxygen measurements taken in Cottonwood Springs Reservoir. The lower dissolved oxygen concentrations occurred in the deeper part of the measured depth profile and were associated with a temperature gradient.

7.4.2.2 Thermal Stratification

Existing summer thermal stratification of Cottonwood Springs Reservoir, in the deep water area near the dam, is described by the depth-profile temperature plots measured during the 2-year period of 2001 through 2002. Temperature depth-profiles measured during the summer were compiled and plotted (Plate 300). The plotted depth-profile temperature measurements indicate that the reservoir showed significant thermal stratification during the summer (Plate 300).

7.4.2.3 Summer Dissolved Oxygen Conditions

Existing summer dissolved oxygen conditions in Cottonwood Springs Reservoir, in the deep water area near the dam, are described by the depth-profile dissolved oxygen plots for the 2-year period 2001 through 2002 (Plate 301). Significant vertical gradients in dissolved oxygen levels occurred during the summer when significant thermal stratification was present. Two profiles indicated anoxic conditions (i.e., dissolved oxygen concentrations < 2.5 mg/l) near the reservoir bottom (Plate 301).

7.4.2.4 Water Clarity

Figure 8.6 displays a box plot of the Secchi depth transparencies measured at the two in-reservoir monitoring sites (i.e., COTLKND1 and COTLKML1) during 2002 (note: the monitoring sites are oriented in an upstream to downstream direction). Water clarity measured at the two sites was very high and similar (Figure 8.6).

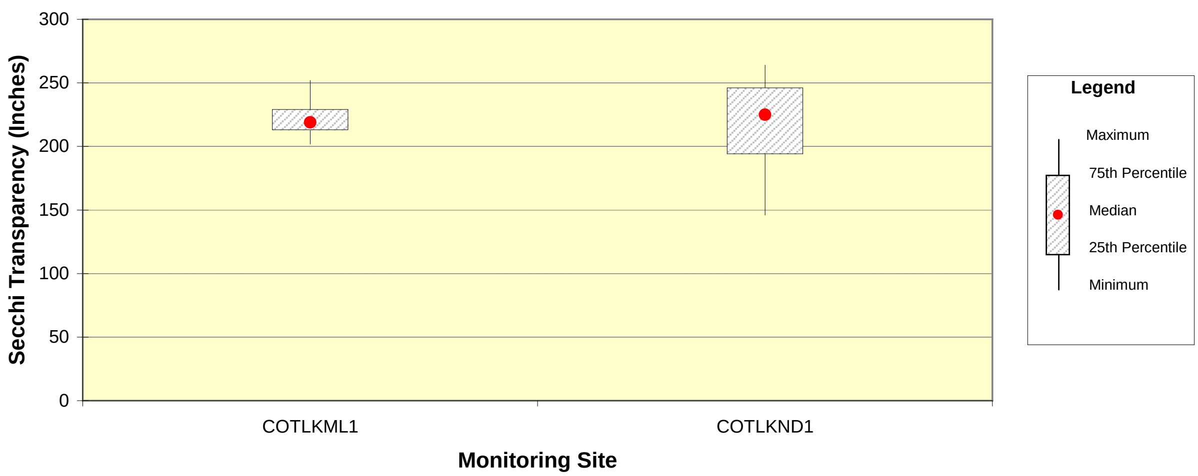

Figure 8.6. Box plot of Secchi depth transparencies measured in Cottonwood Springs Reservoir during 2002.

7.4.2.5 Reservoir Trophic State

Trophic State Index (TSI) values for Cottonwood Springs Reservoir were calculated from monitoring data collected during the 3-year period 2001 through 2003 at the near-dam ambient monitoring site (i.e., COTLKND1). Table 8.3 summarizes the TSI values calculated for the reservoir. The TSI values indicate that Cottonwood Springs Reservoir is in a mesotrophic condition.

Table 8.3. Summary of Trophic State Index (TSI) values calculated for Cottonwood Springs Reservoir for the 3-year period of 2001 through 2003.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	6	32	35	34	41
TSI(TP)	6	41	50	52	57
TSI(Chl)	2	40	40	40	40
TSI(Avg)	6	36	43	43	49

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values.

Note: See Section 4.1.3 for discussion of TSI calculation.

8 WATER QUALITY MONITORING AND MANAGEMENT ACTIVITIES PLANNED FOR FUTURE YEARS

8.1 WATER QUALITY DATA COLLECTION

A tentative schedule of water quality monitoring targeted for implementation over the next 5 years at the District's Tributary Projects is given in Table 9.1. The identified data collection activities are considered the minimum needed to allow for the periodic assessment of water quality conditions. The actual monitoring activities that are implemented will be dependent upon the availability of future resources.

8.2 TOTAL MAXIMUM DAILY LOADS (TMDLS)

The District will provide water quality information to the States for 303(d) listing consideration and participate, as appropriate, as a stakeholder in the development and implementation of TMDLs on waterbodies that involve Tributary Projects.

Table 9.1. Water quality monitoring planned for District Tributary Projects over the next 5 years and the intended data collection approach. Actual monitoring activities implemented will be dependent upon available resources.

Waterbodies to be Monitored	Long-Term Fixed Station Monitoring	Intensive Surveys	Special Studies	Investigative Monitoring
Colorado Tributary Project Areas:				
• Bear Creek, Chatfield, and Cherry Creek Reservoirs	Other[a]			
Nebraska Tributary Project Areas:				
• Salt Creek and Papillion Creek Reservoirs	X[b]			
North Dakota Tributary Project Areas:				
• Bowman-Haley and Pipestem Reservoirs	2010 2013			
South Dakota Tributary Project Areas:				
• Cold Brook and Cottonwood Springs Reservoirs	2011 2014			

[a] The District will utilize water quality data collected by the Local Watershed Management Authorities.
[b] Tentatively identified to be monitored every year. The level of monitoring is dependent upon the continuance of a monitoring partnership with the Nebraska Department of Environmental Quality.

9 REFERENCES

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10 PLATES

Plate 1. Summary of water quality conditions monitored in Ed Zorinsky Reservoir at site EZRLKND1 from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	26	1110.7	1110.5	1108.9	1115.0	-----	-----	-----
Water Temperature (°C)	0.1	394	21.7	21.8	12.4	29.4	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	394	5.3	5.9	0.1	12.7	≥ 5(2)	104	30%
Dissolved Oxygen (% Sat.)	0.1	372	60.9	70.7	1.0	153.4	-----	-----	-----
Specific Conductance (umho/cm)	1	382	470	494	291	633	2,000(3)	0	0%
pH (S.U.)	0.1	373	7.8	7.9	6.7	8.7	≥6.5 & ≤9.0(1)	0	0%
Turbidity (NTUs)	1	372	38	13	0	3000	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	382	252	258	-136	504	-----	-----	-----
Secchi Depth (in.)	1	25	36	27	12	95	-----	-----	-----
Alkalinity, Total (mg/l)	7	50	134	131	100	170	>20(1)	0	0%
Ammonia, Total (mg/l)	0.02	50	-----	0.1	n.d.	2.7	11.1 (4,5), 1.87 (4,6)	0, 1	0%, 2%
Chlorophyll *a* (ug/l) – Field Probe	1	323	23	18	1	112	10(7)	227	70%
Chlorophyll *a* (ug/l) – Lab Determined	1	25	30	29	2	85	10(7)	18	72%
Hardness, Total (mg/l)	0.4	5	129.2	131.0	120.0	139.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	50	1.2	1.1	n.d.	4.5	-----	-----	-----
Nitrogen, Total (mg/)	0.1	50	1.3	1.2	n.d.	4.8	1(7)	30	60%
Nitrate-Nitrite N, Total (mg/l)	0.02	50	-----	0.03	n.d.	0.40	100(3)	0	0%
Phosphorus, Total (mg/l)	0.02	50	0.09	0.07	n.d.	0.54	0.05(7)	39	78%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	-----	n.d.	n.d.	0.19	-----	-----	-----
Suspended Solids, Total (mg/l)	4	30	-----	6	n.d.	55	-----	-----	-----
Aluminum, Dissolved (ug/l)	25	5	-----	n.d.	n.d.	333	750(5), 87(6)	0, 1	0, 20%
Antimony, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	88(5), 30(6)	0	0%
Arsenic, Dissolved (ug/l)	3	5	-----	3	n.d.	4	340(5), 16.7(8)	0	0%
Beryllium, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	130(5), 5.3(6)	0	0%
Cadmium, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	7.7(5), 0.3(6)	0	0%
Chromium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	10	739(5), 96(6)	0	0%
Copper, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	2	17(5), 11(6)	0	0%
Lead, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	87(5), 3.3(6)	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4(5)	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77(6)	0	0%
Nickel, Dissolved (ug/l)	3	5	-----	n.d.	n.d.	60	588(5), 65(6)	0,1	0%
Selenium, Total (ug/l)	2	5	-----	2	n.d.	2	20(3,5), 5(6)	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	5.5(5)	0	0%
Thallium (ug/l)	6	5	-----	n.d.	n.d.	n.d.	1,400(5), 6.3(8)	0	0%
Zinc, Dissolved (ug/l)	3	5	-----	n.d.	n.d.	n.d.	147(5,6)	0	0%
Microcystin, Total (ug/l)	0.05	25	-----	n.d.	n.d.	0.64	20(9)	0	0%
Acetochlor, Total (ug/l)(C)	0.05	15	-----	n.d.	n.d.	1.00	-----	-----	-----
Alachlor, Total (ug/l)(C)	0.05	10	-----	n.d.	n.d.	n.d.	760(5), 76(6)	0	0%
Atrazine, Total (ug/l)(C)	0.05	25	0.27	0.30	n.d.	0.70	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l)(C)	0.05	25	-----	n.d.	n.d.	0.50	390(5), 100(6)	0	0%
Pesticide Scan (ug/l)(D)	0.05						-----	-----	-----
Acetochlor		5	-----	n.d.	n.d.	1.00	-----	-----	-----
Atrazine		5	-----	n.d.	n.d.	0.35	330(5), 12(6)	0	0%
Profluralin		1	-----	0.48	0.48	0.48	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l microcystins in recreation water for impairment assessment.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 2. Summary of water quality conditions monitored in Ed Zorinsky Reservoir at site EZRLKML1B from May to September during the 5-year period 2006 through 2010. [Note: Except for pool elevation and Secchi depth, results are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	25	1110.7	1110.5	1108.9	1115.0	-----	-----	-----
Water Temperature (°C)	0.1	398	21.7	21.8	12.7	30.2	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	398	5.2	6.1	0.1	13.2	≥ 5(2)	164	41%
Dissolved Oxygen (% Sat.)	0.1	368	61.4	70.2	1.1	142.8	-----	-----	-----
Specific Conductance (umho/cm)	1	382	470	496	272	640	2,000(3)	0	0%
pH (S.U.)	0.1	368	7.8	7.9	6.7	8.8	≥6.5 & ≤9.0(1)	0	0%
Turbidity (NTUs)	1	368	35	13	1	1048	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	382	270	285	-136	425	-----	-----	-----
Secchi Depth (in.)	1	26	32	26	10	86	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	317	25	18	2	132	10(4)	228	72%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).
(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 3. Summary of water quality conditions monitored in Ed Zorinsky Reservoir at site EZRLKML1A from May to September during the 2-year period 2009 through 2010. [Note: Except for pool elevation and Secchi depth, results are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	9	1110.8	1110.5	1110.3	1111.5	-----	-----	-----
Water Temperature (°C)	0.1	175	20.8	20.6	11.7	29.5	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	175	4.7	4.3	0.1	12.4	≥ 5(2)	95	54%
Dissolved Oxygen (% Sat.)	0.1	175	54.5	49.2	0.7	148.3	-----	-----	-----
Specific Conductance (umho/cm)	1	175	500	543	311	646	2,000(3)	-----	-----
pH (S.U.)	0.1	175	7.8	7.7	6.8	8.7	≥6.5 & ≤9.0(1)	0	0%
Turbidity (NTUs)	1	175	16	12	0	308	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	175	222	243	-143	429	-----	-----	-----
Secchi Depth (in.)	1	10	27	24	18	38	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	175	35	29	8	139	10(4)	170	97%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).
(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life .
* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 4. Summary of water quality conditions monitored in Ed Zorinsky Reservoir at site EZRLKML2 from May to September during the 3-year period 2008 through 2010. . [Note: Except for pool elevation and Secchi depth, results are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	15	1111.1	1110.6	1110.3	1115.0	-----	-----	-----
Water Temperature (°C)	0.1	195	22.3	22.3	13.9	30.2	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	195	6.2	6.6	0.2	13.0	≥ 5(2)	55	28%
Dissolved Oxygen (% Sat.)	0.1	195	74.4	80.9	2.1	144.1	-----	-----	-----
Specific Conductance (umho/cm)	1	195	437	388	225	642	2,000(3)	-----	-----
pH (S.U.)	0.1	195	8.0	8.0	7.0	8.9	≥6.5 & ≤9.0(1)	0	0%
Turbidity (NTUs)	1	195	81	17	1	1812	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	195	293	308	-127	443	-----	-----	-----
Secchi Depth (in.)	1	16	25	23	6	74	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	194	34	26	1	125	16(4)	163	84%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).
(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life .
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aesthetics.
* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 4. Summary of water quality conditions monitored in Ed Zorinsky Reservoir at site EZRLKUP1 from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for other parameters are for "grab samples" collected at ½ the measured Secchi depth.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	26	1110.7	1110.5	1108.9	1115.0	-----	-----	-----
Water Temperature (°C)	0.1	157	23.0	23.4	13.1	31.1	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	157	7.4	6.9	0.5	15.9	≥ 5(2)	25	16%
Dissolved Oxygen (% Sat.)	0.1	145	89.5	83.9	6.9	171.8	-----	-----	-----
Specific Conductance (umho/cm)	1	151	438	445	167	621	2,000(3)	0	0%
pH (S.U.)	0.1	151	8.1	8.1	7.2	8.8	≥6.5 & ≤9.0(1)	0, 5	0%, 3%
Turbidity (NTUs)	1	143	174	38	13	3754	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	151	306	307	-34	444	-----	-----	-----
Secchi Depth (in.)	1	26	15	14	2	30	-----	-----	-----
Alkalinity, Total (mg/l)	7	25	131	130	98	170	>20(1)	0	0%
Ammonia, Total (mg/l)	0.02	25	-----	0.06	n.d.	0.34	6.95 (4,5), 1.18 (4,6)	0	0%
Chlorophyll *a* (ug/l) – Field Probe	1	119	33	28	n.d.	152	10(7)	97	82%
Chlorophyll *a* (ug/l) – Lab Determined	1	25	37	36	n.d.	132	10(7)	18	72%
Hardness, Total (mg/l)	0.4	5	130.4	134.0	120.0	136.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	25	1.1	1.1	n.d.	3.1	-----	-----	-----
Nitrogen, Total (mg/)	0.1	25	1.3	1.2	n.d.	3.9	1 (7)	17	68%
Nitrate-Nitrite N, Total (mg/l)	0.02	25	-----	0.05	n.d.	0.80	100(3)	0	0%
Phosphorus, Total (mg/l)	0.02	25	0.11	0.11	0.02	0.23	0.05(7)	23	92%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	25	-----	0.02	n.d.	0.08	-----	-----	-----
Suspended Solids, Total (mg/l)	4	25	24	22	5	68	-----	-----	-----
Aluminum, Dissolved (ug/l)	25	5	-----	n.d.	n.d.	5	750(5), 87(6)	0	0%
Antimony, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	88(5), 30(6)	0	0%
Arsenic, Dissolved (ug/l)	3	5	-----	3	n.d.	4	340(5), 16.7(8)	0	0%
Beryllium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	130(5), 5.3(6)	0	0%
Cadmium, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	7.8(5), 0.3(6)	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	752 (5), 98(6)	0	0%
Copper, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	18(5), 12(6)	0	0%
Lead, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	89(5), 3.5(6)	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4(5)	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77(6)	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	600(5), 67(6)	0	0%
Selenium, Total (ug/l)	2	5	-----	2	n.d.	2	20(3,5), 5(6)	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	5.7(5)	0	0%
Thallium (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	1,400(5), 6.3(8)	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	150(5,6)	0	0%
Microcystin, Total (ug/l)	0.05	25	-----	n.d.	n.d.	0.40	20(9)	0	0%
Acetochlor, Total (ug/l)(C)	0.05	15	-----	0.10	n.d.	0.80	-----	-----	-----
Alachlor, Total (ug/l)(C)	0.05	10	-----	n.d.	n.d.	0.05	760(5), 76(6)	0	0%
Atrazine, Total (ug/l)(C)	0.05	25	0.28	0.20	n.d.	0.80	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l)(C)	0.05	20	-----	n.d.	n.d.	0.40	390(5), 100(6)	0	0%
Pesticide Scan (ug/l)(D)	0.05						-----	-----	-----
Acetochlor		5	-----	n.d.	n.d.	0.20	-----	-----	-----
Atrazine		5	-----	n.d.	n.d.	0.37	330(5), 12(6)	0	0%
Metolachlor		5	-----	n.d.	n.d.	0.13	390(5), 100(6)	0	0%
Metribuzin		5	-----	n.d.	n.d.	0.10	100(6)	0	0%
Profluralin		1	-----	0.59	0.59	0.59	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l microcystins in recreation water for impairment assessment.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

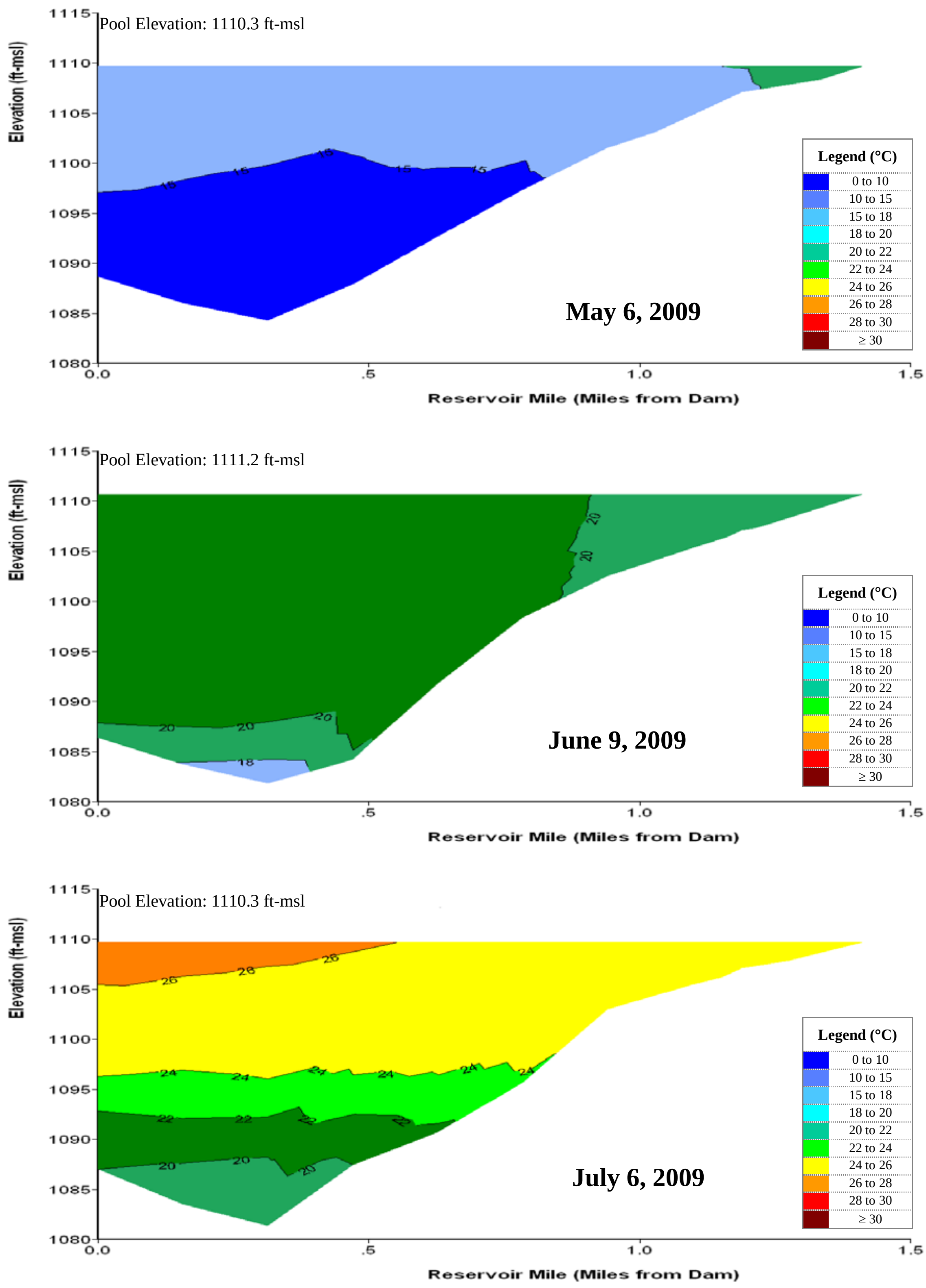
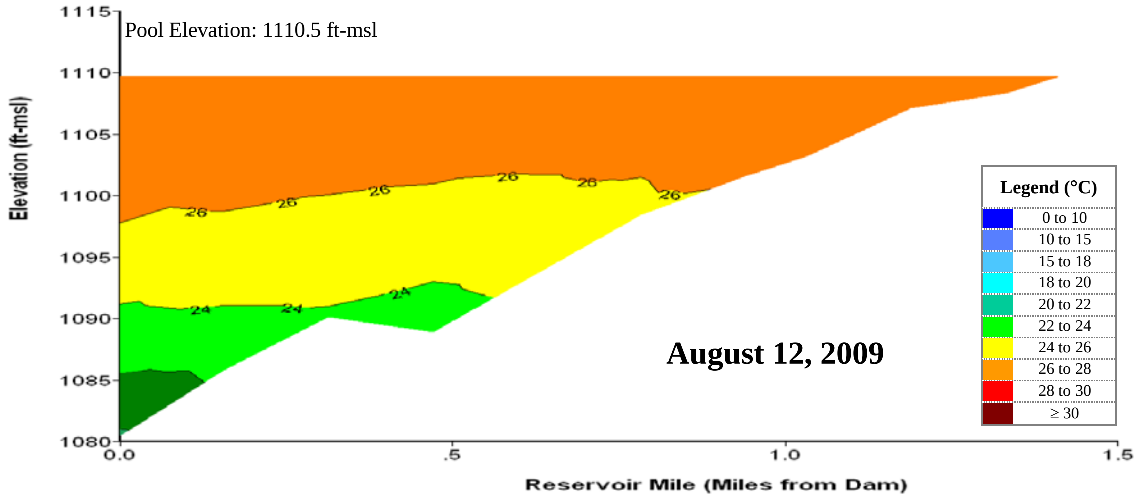


Plate 5. Longitudinal water temperature contour plots of Ed Zorinsky Reservoir based on depth-profile water temperatures (°C) measured from May to September 2009.



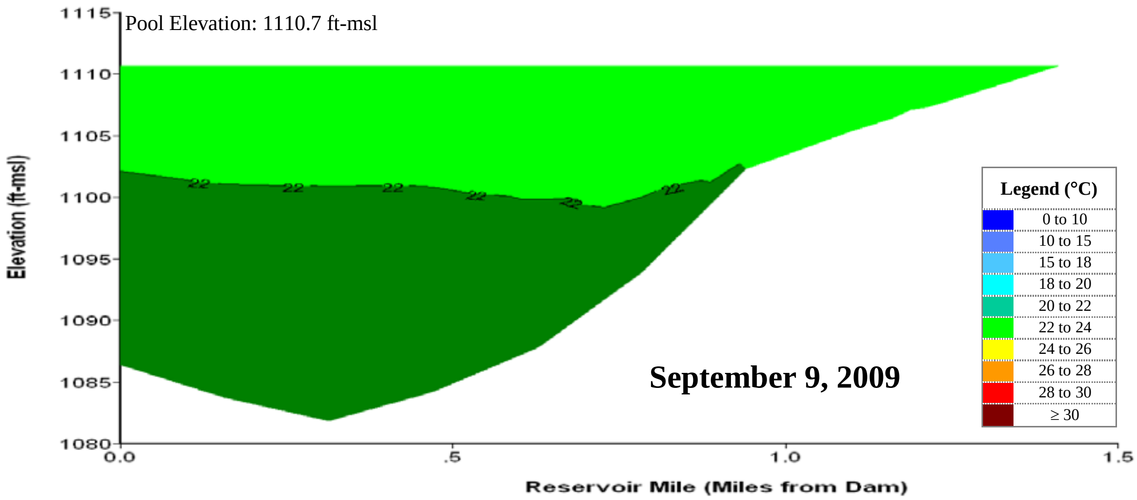


Plate 5. (Continued).

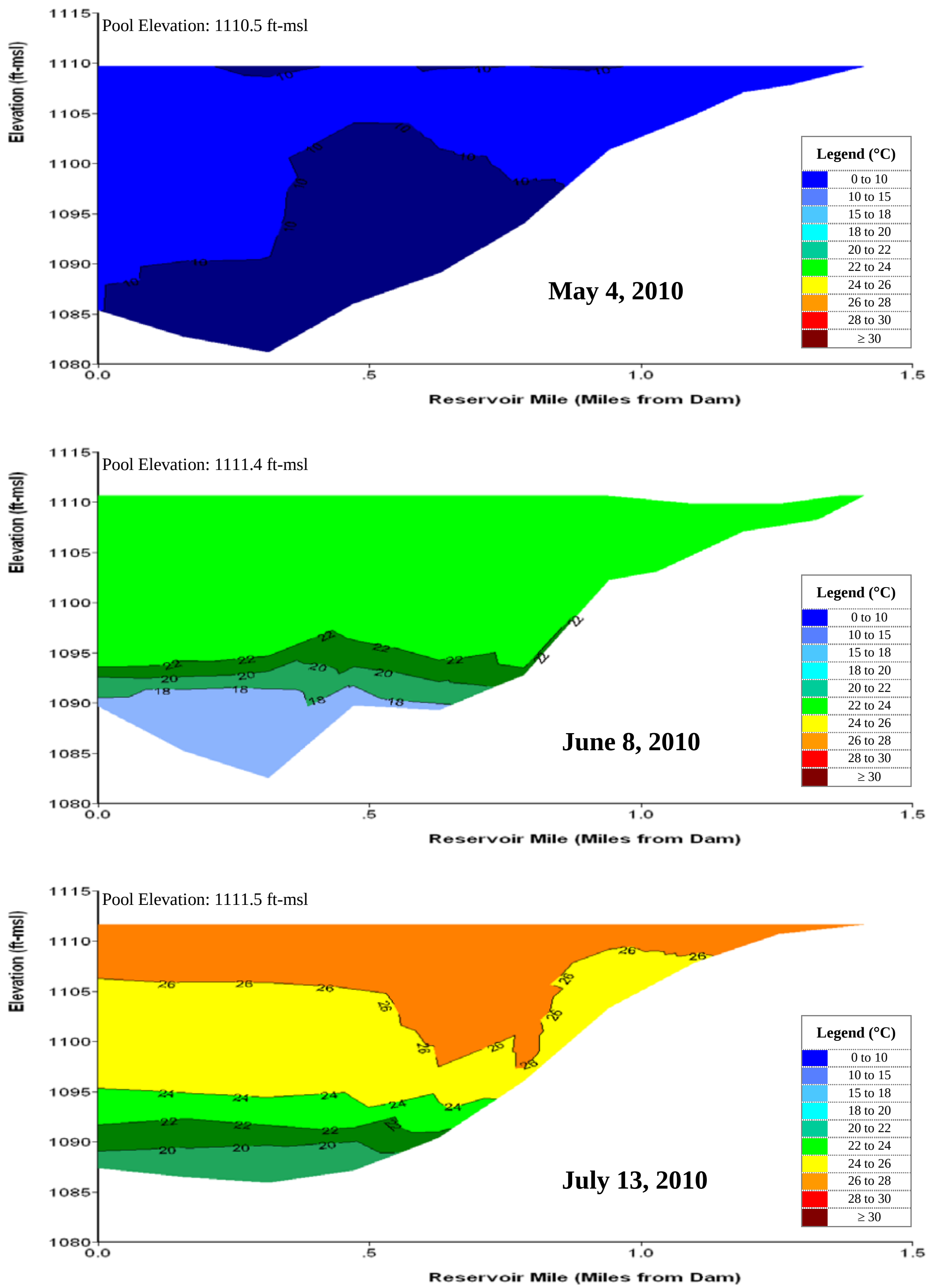
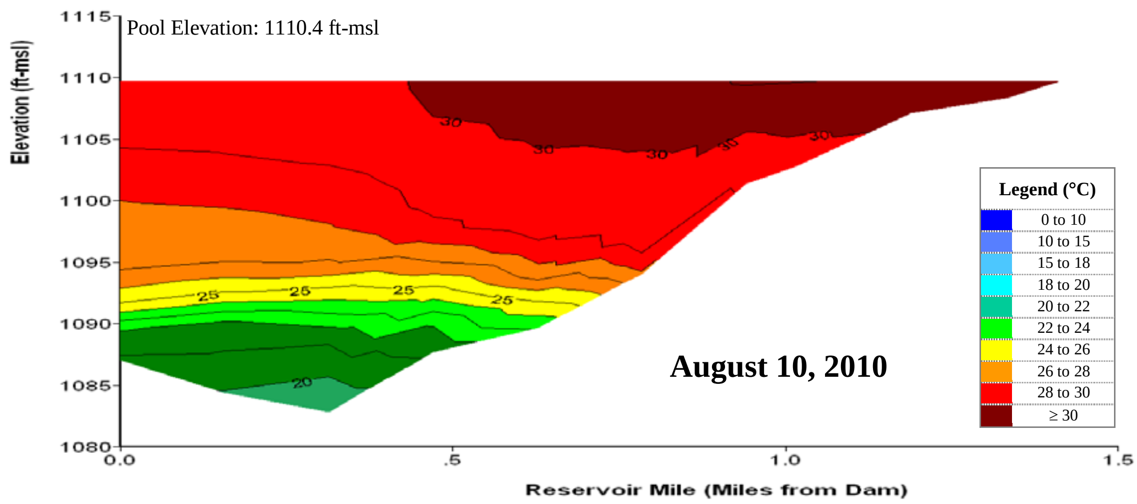


Plate 6. Longitudinal water temperature contour plots of Ed Zorinsky Reservoir based on depth-profile water temperatures (°C) measured at sites EZRLKND1, EZRLKML1A, EZRLKML1B, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2010.



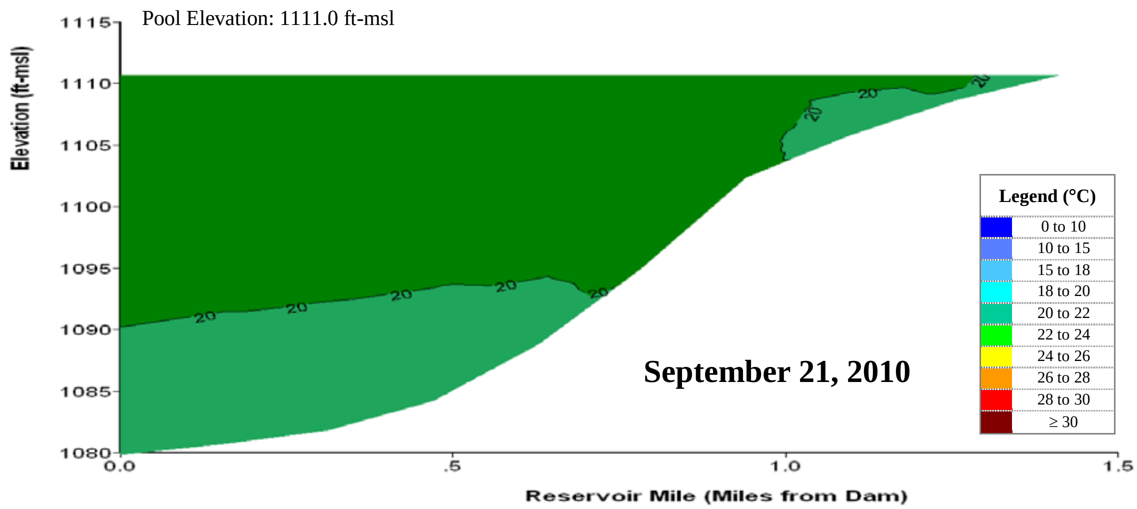


Plate 6. (Continued).

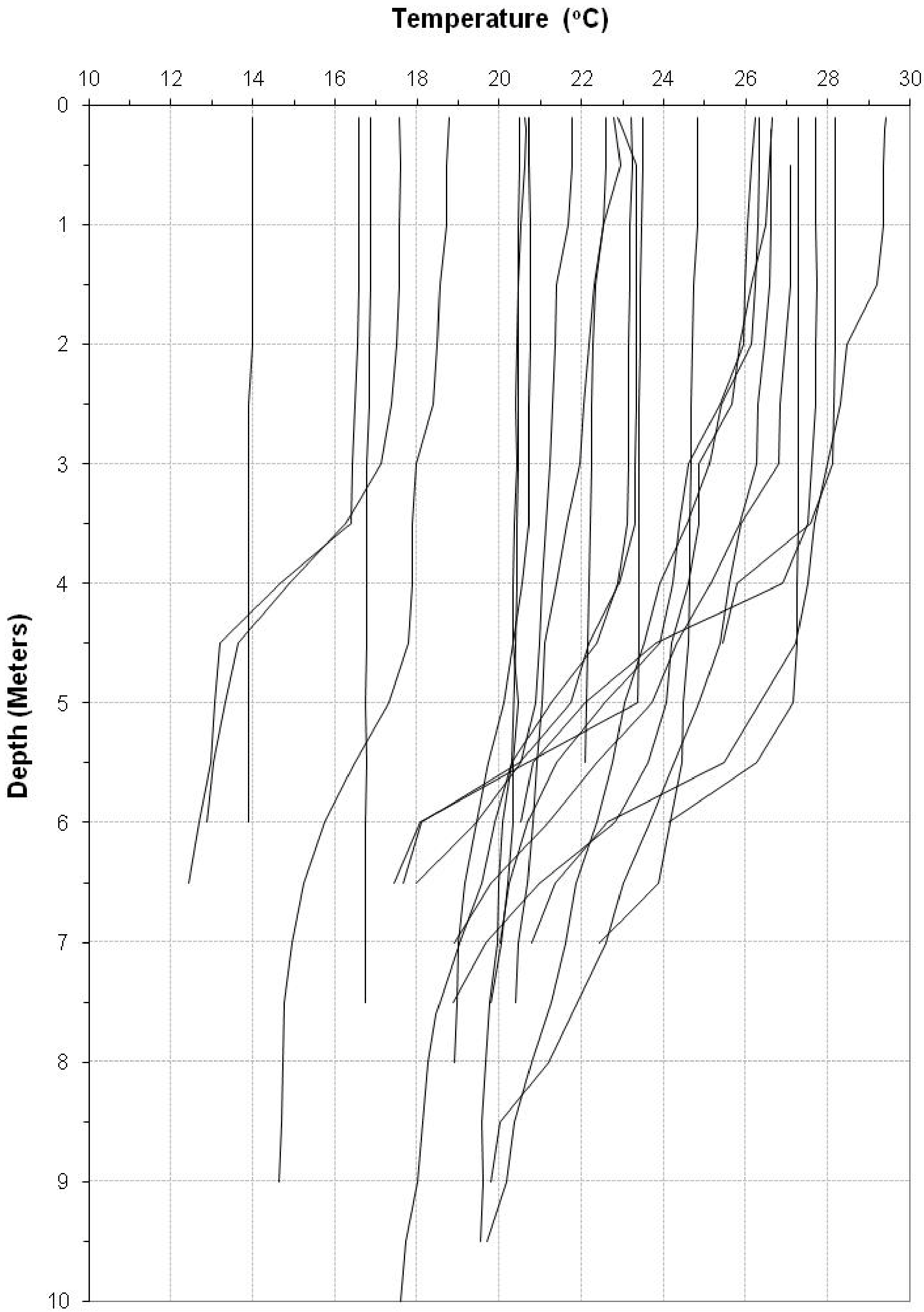


Plate 7. Temperature depth profiles for Ed Zorinsky Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2006 through 2010.

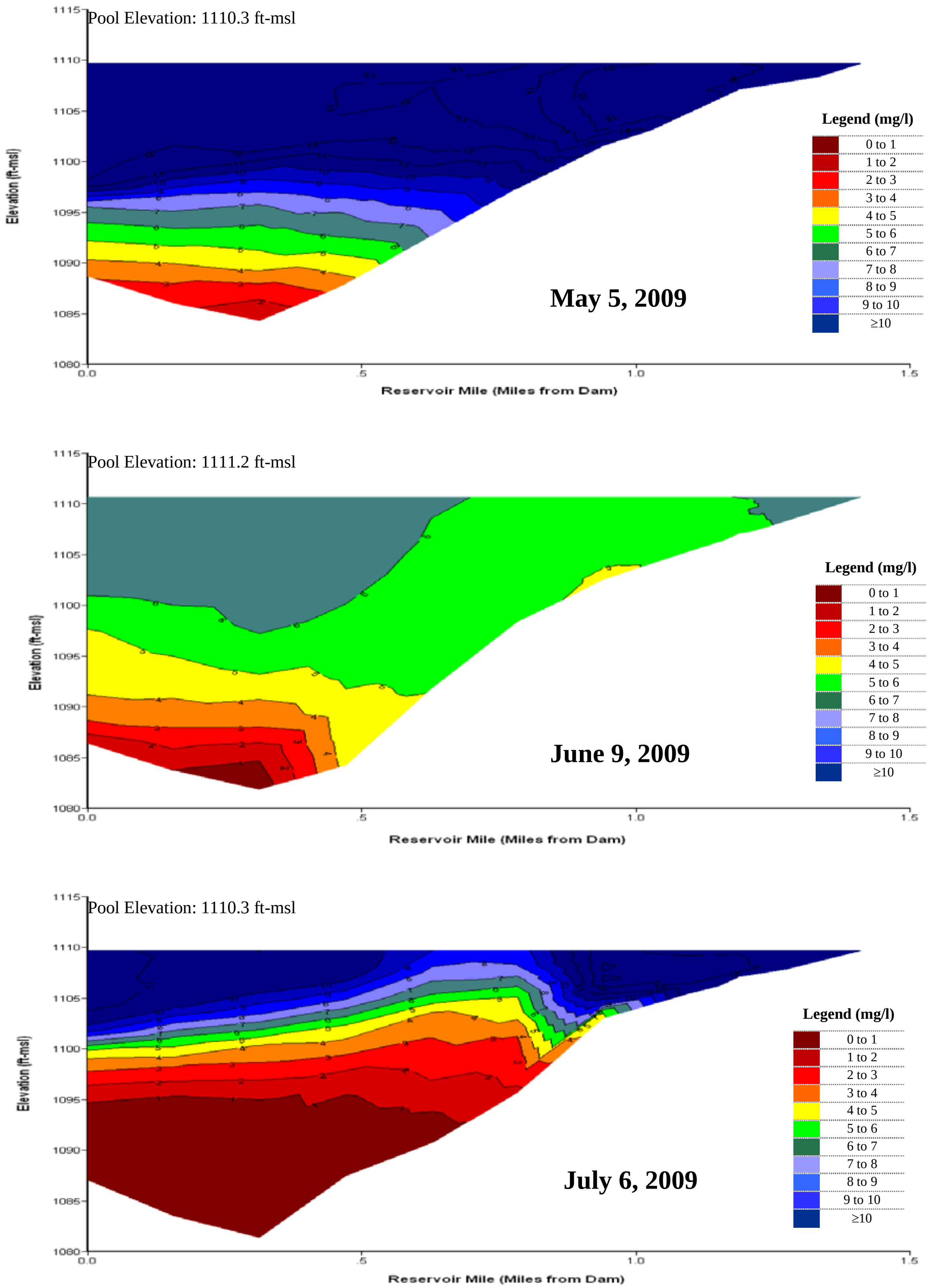
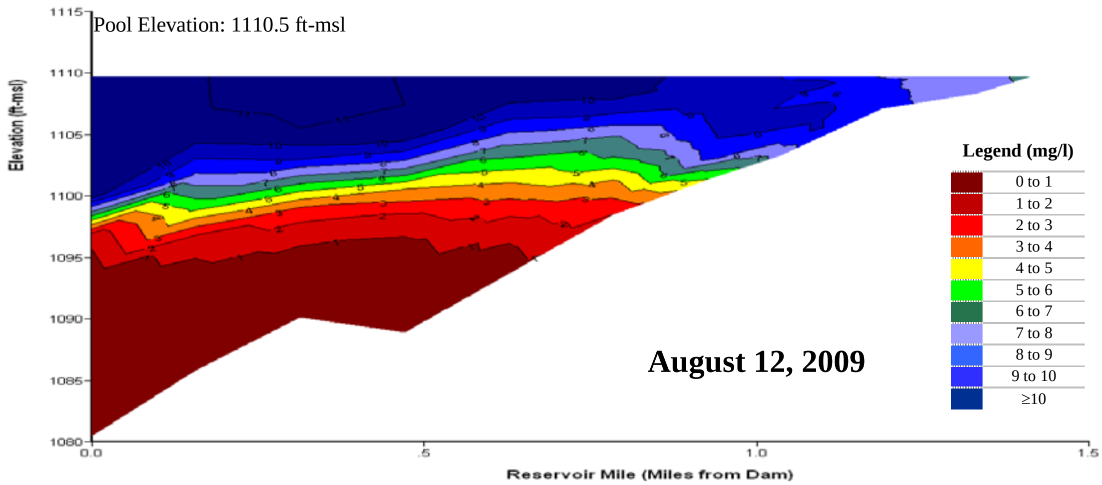


Plate 8. Longitudinal dissolved oxygen contour plots of Ed Zorinsky Reservoir based on depth-profile dissolved oxygen concentrations (mg/l) measured from May to September 2009.



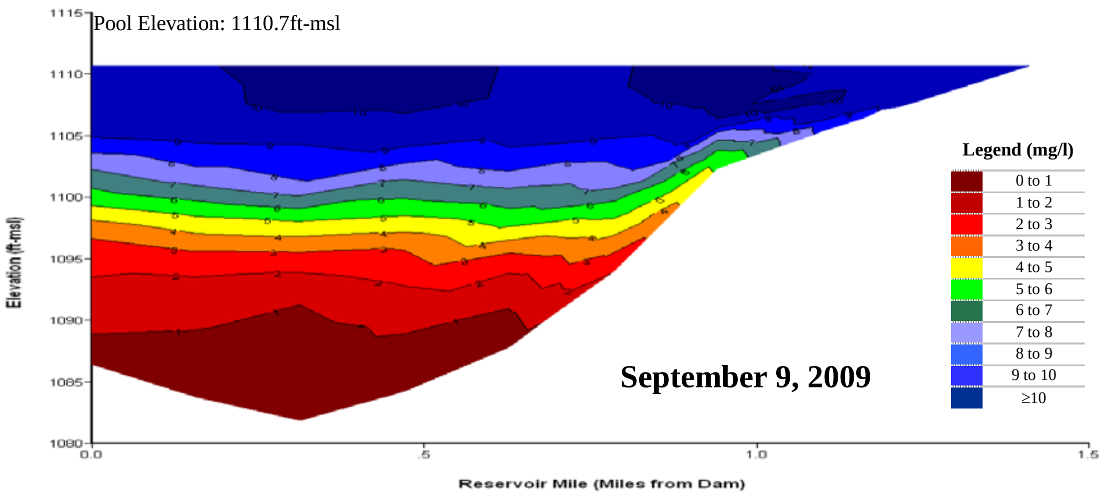


Plate 8. (Continued).

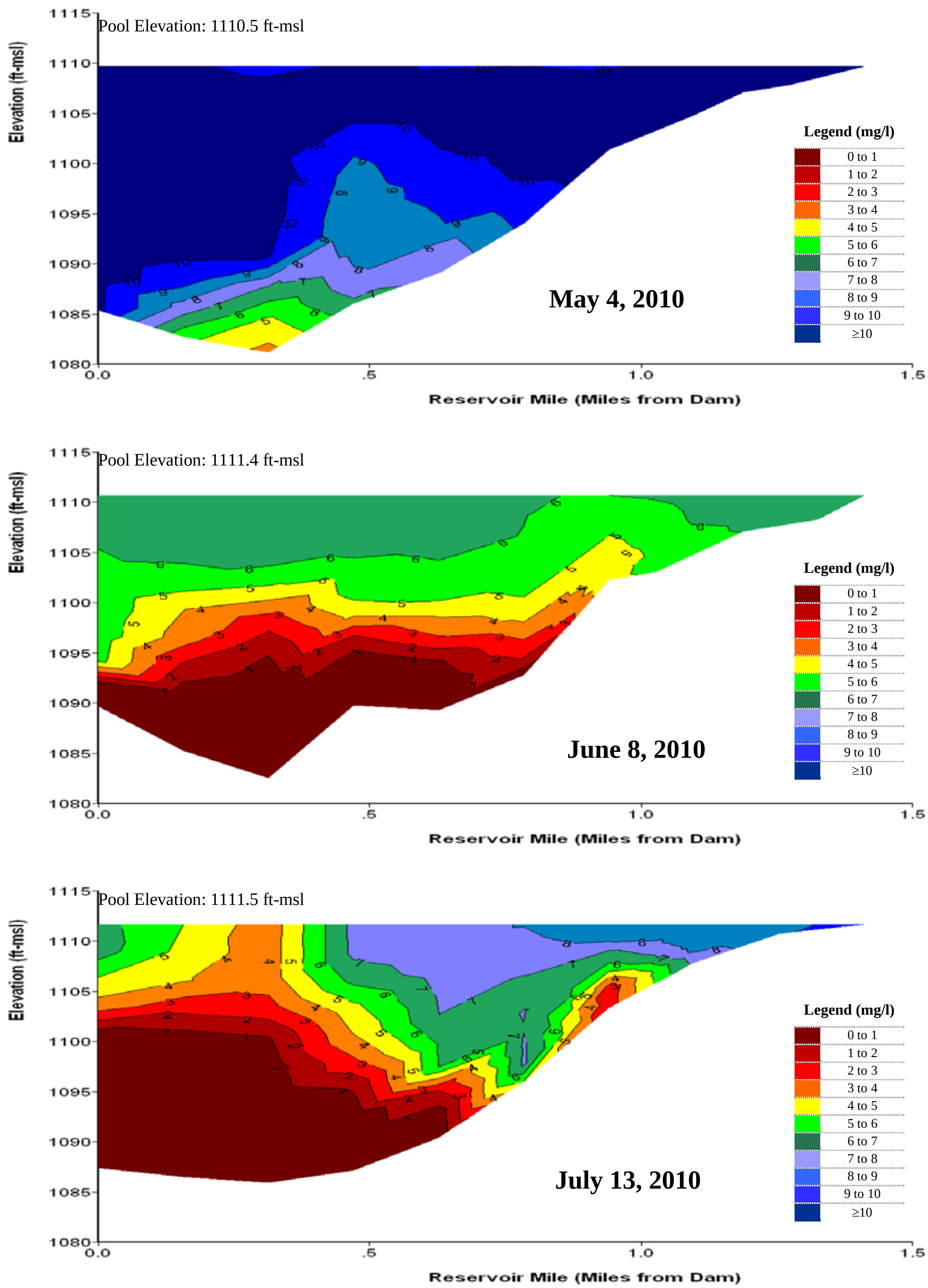
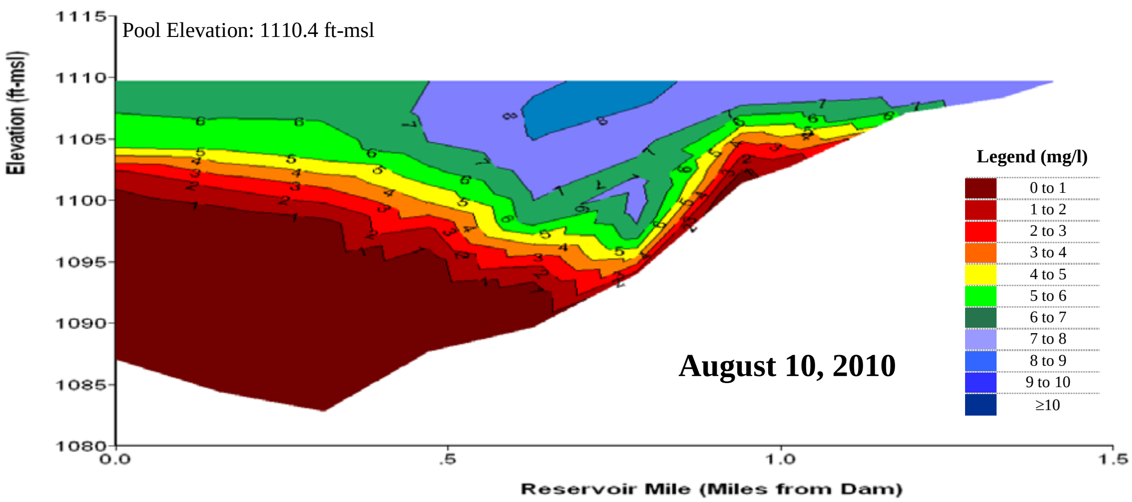


Plate 9. Longitudinal dissolved oxygen contour plots of Ed Zorinsky Reservoir based on depth-profile dissolved oxygen concentrations (mg/l) measured at sites EZRLKND1, EZRLKML1A, EZRLKML1B, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2010.



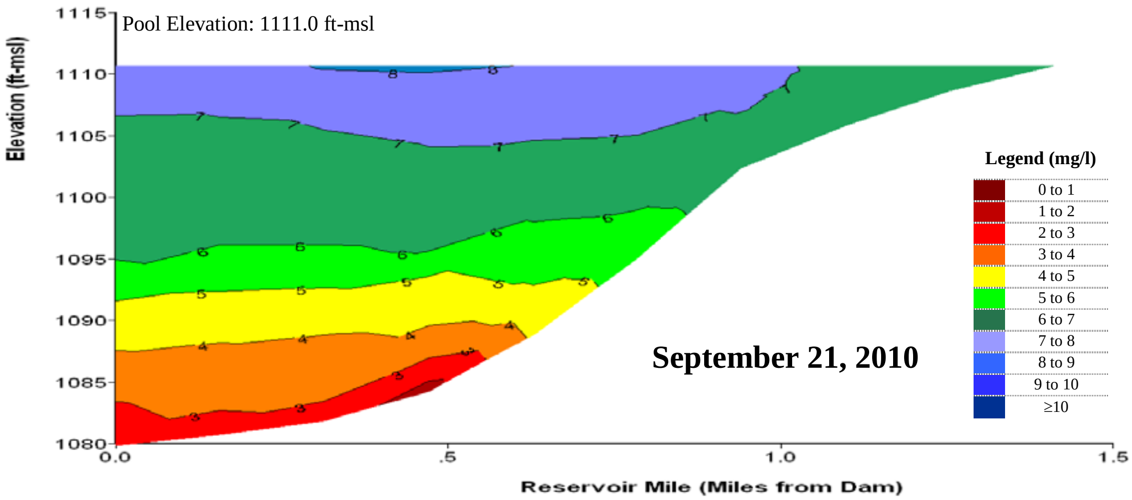


Plate 9. (Continued).

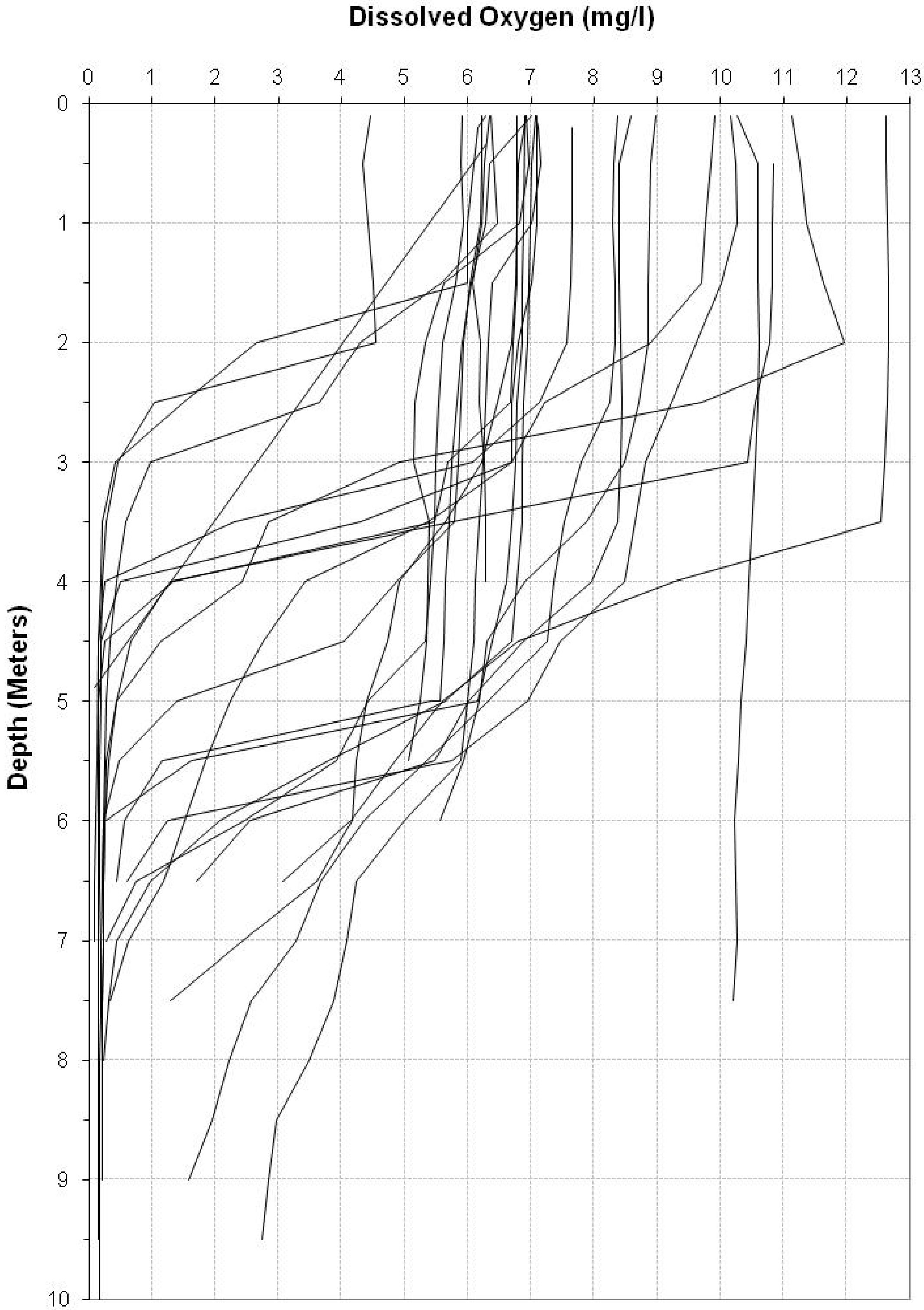


Plate 10. Dissolved oxygen depth profiles for Ed Zorinsky Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2006 through 2010.

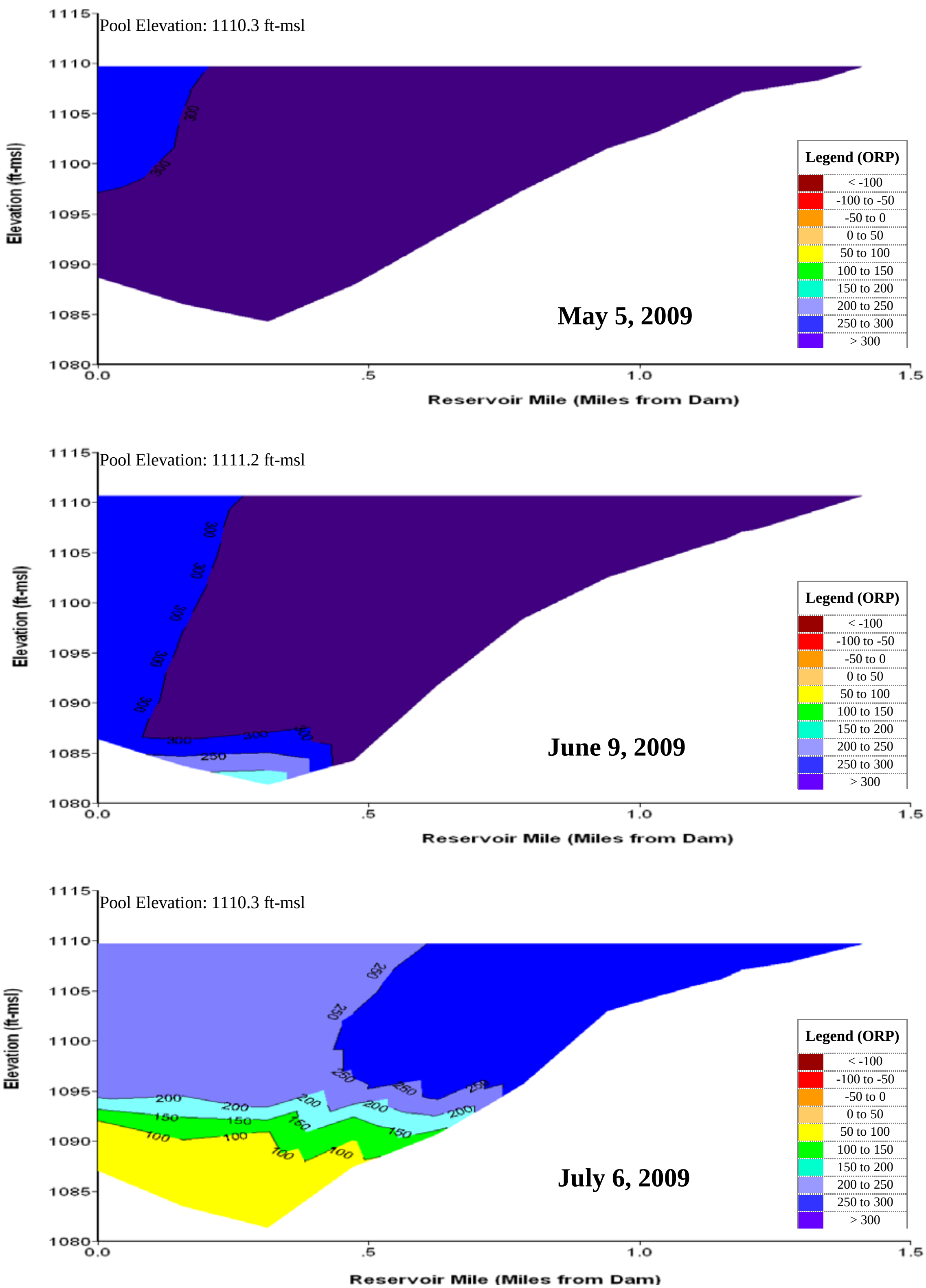
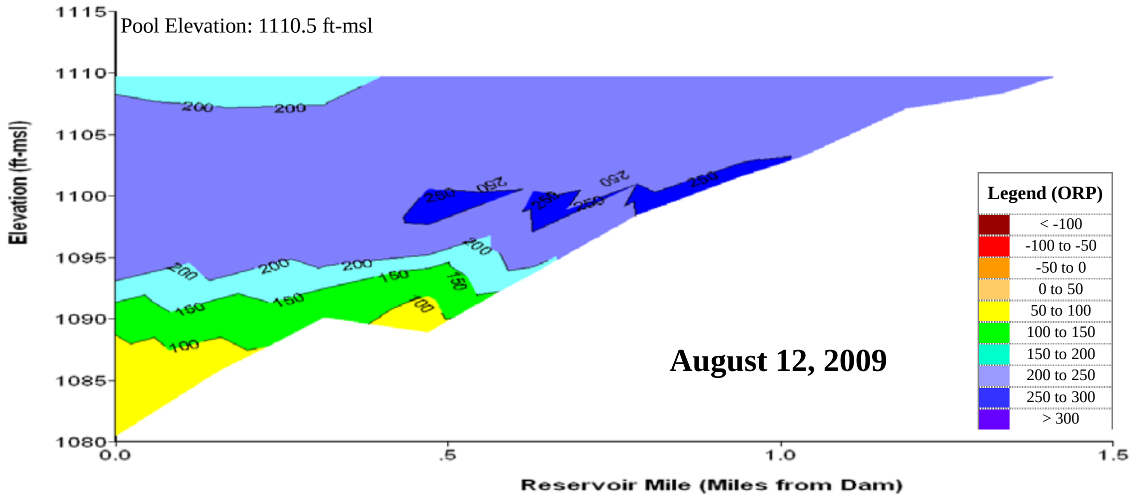


Plate 11. Longitudinal oxidation-reduction potential (ORP) contour plots of Ed Zorinsky Reservoir based on depth-profile ORP levels (mV) measured from May to September 2009.



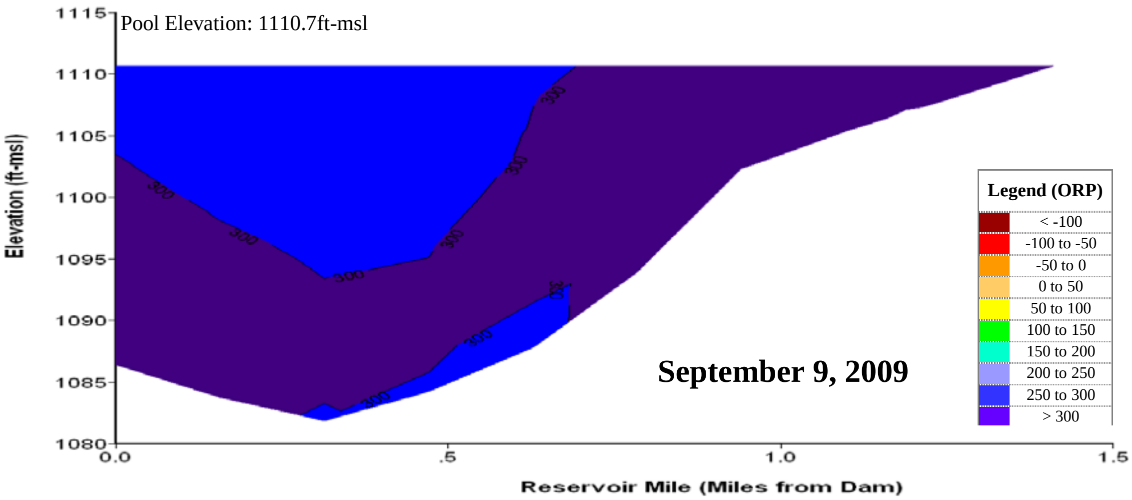


Plate 11. (Continued).

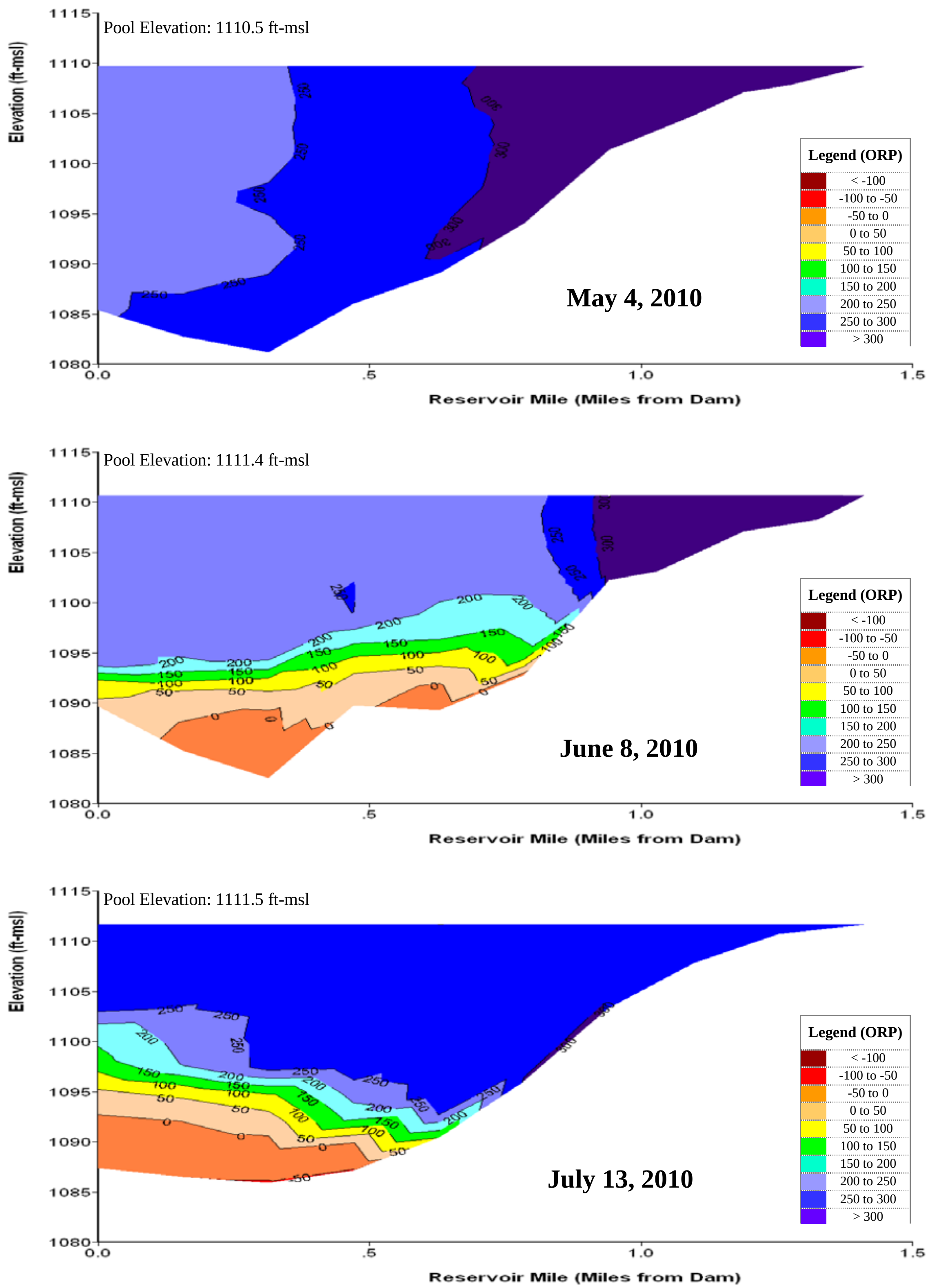
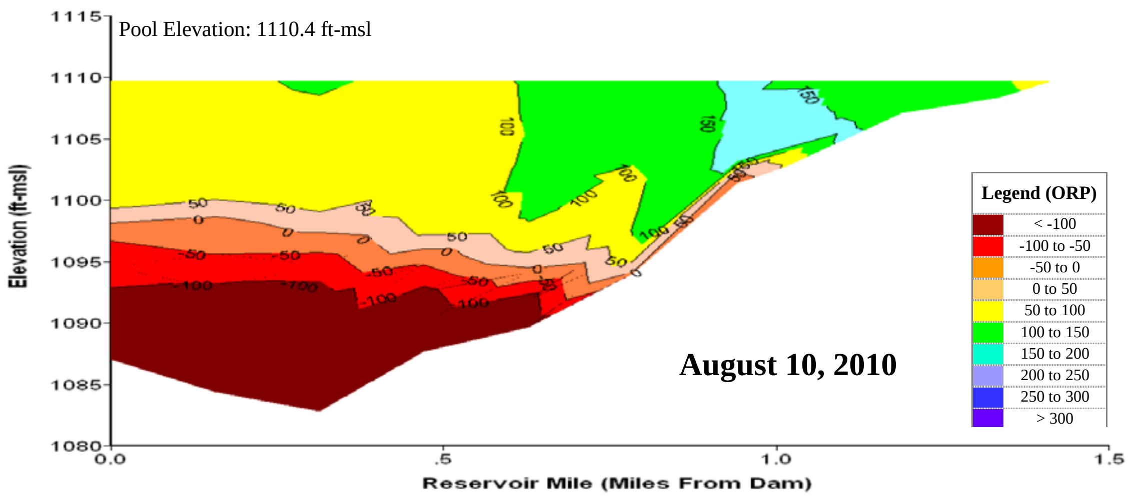


Plate 12. Longitudinal oxidation-reduction potential (ORP) contour plots of Ed Zorinsky Reservoir based on depth-profile ORP levels (mV) measured at sites EZRLKND1, EZRLKML1A, EZRLKML1B, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2010.



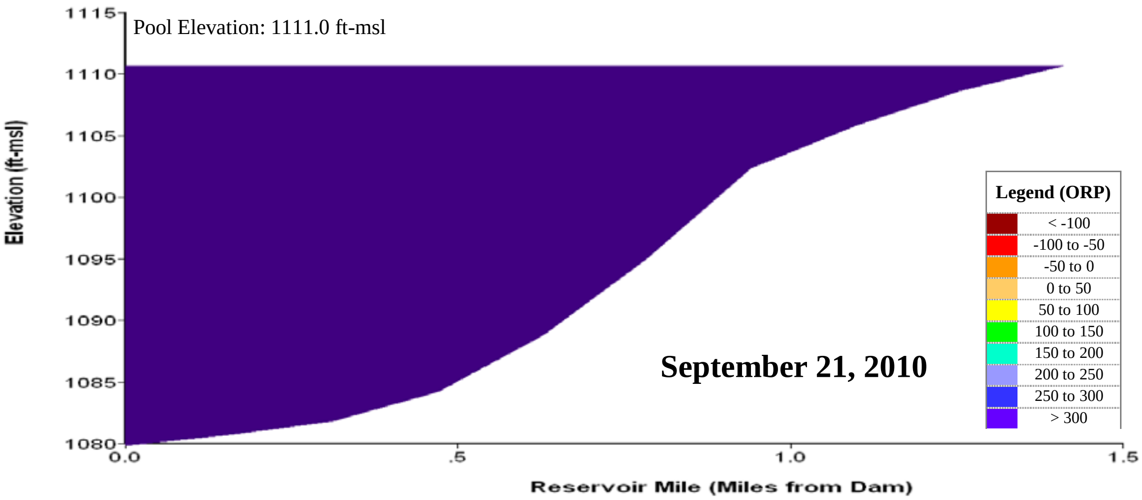


Plate 12. (Continued).

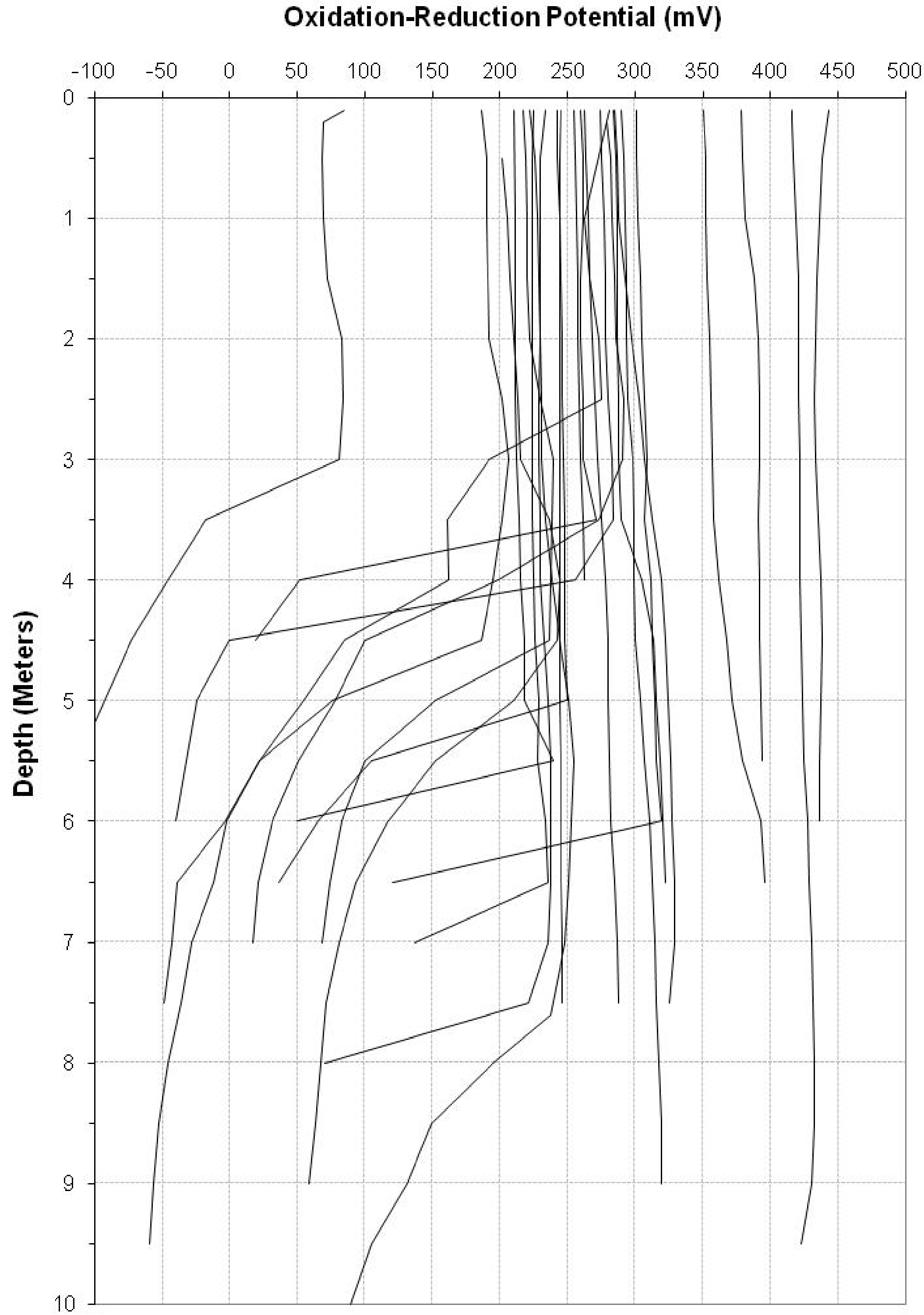


Plate 13. Oxidation-reduction potential depth profiles for Ed Zorinsky Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2006 through 2010.

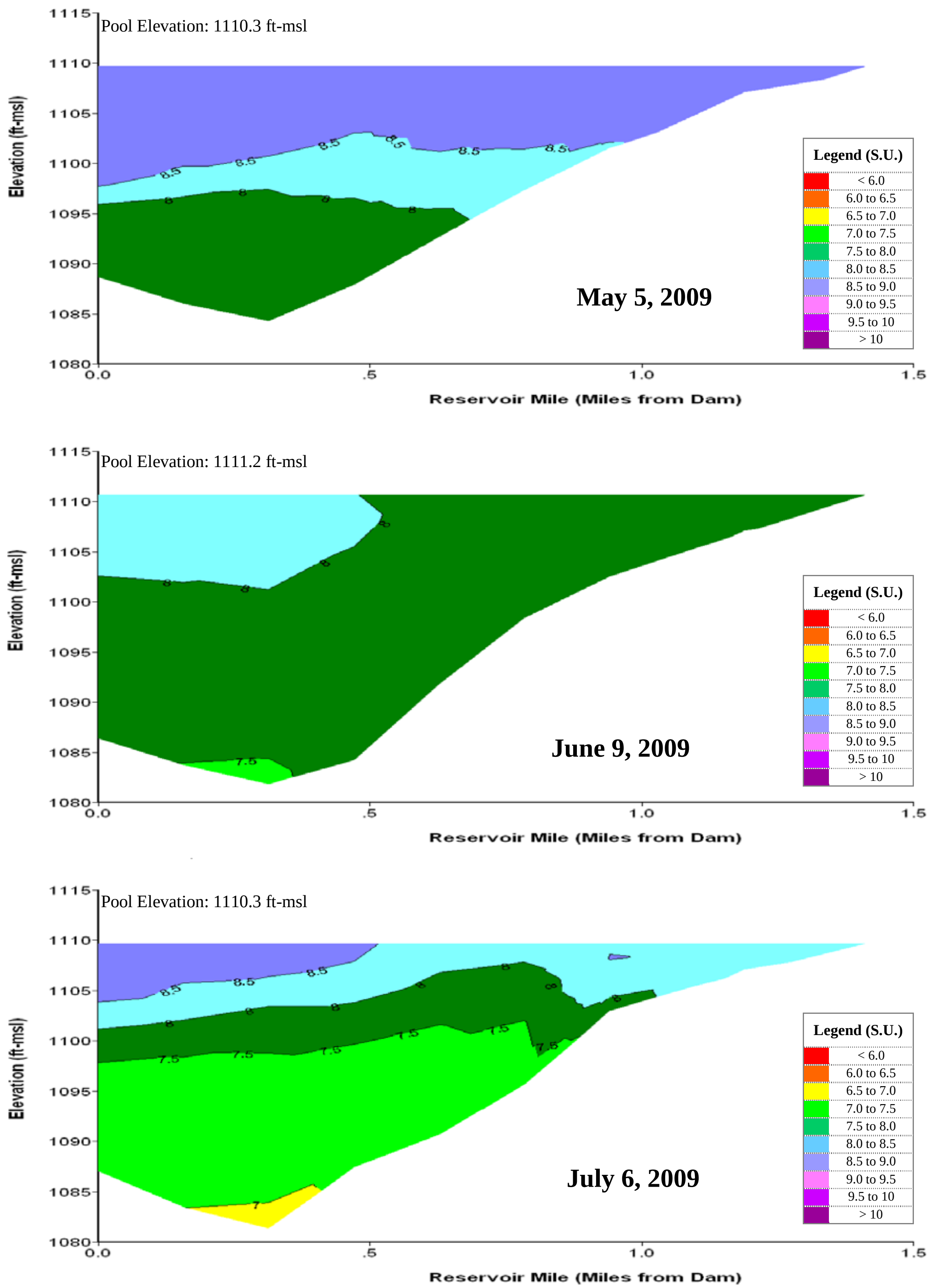
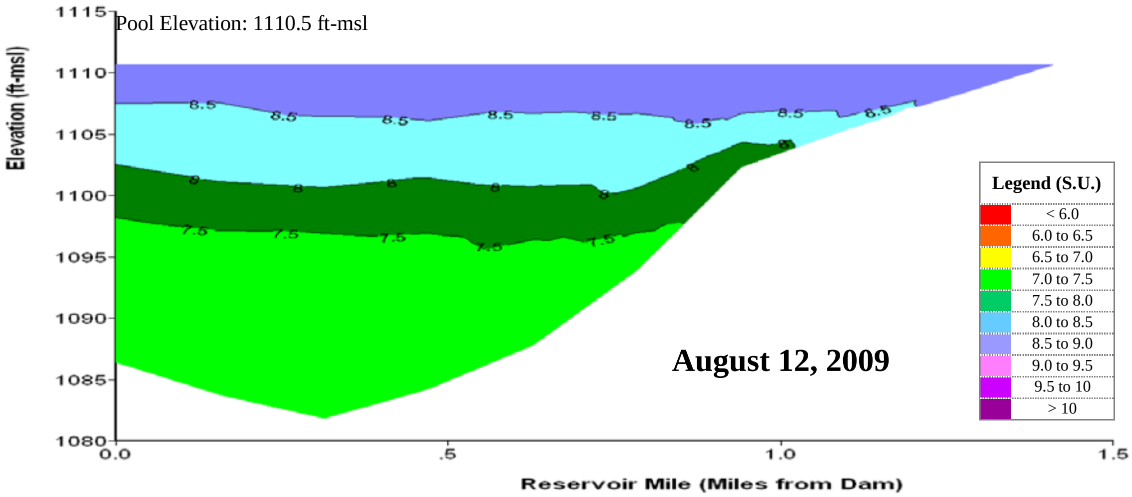


Plate 14. Longitudinal pH contour plots of Ed Zorinsky Reservoir based on depth-profile pH levels (S.U.) measured from May to September 2009.



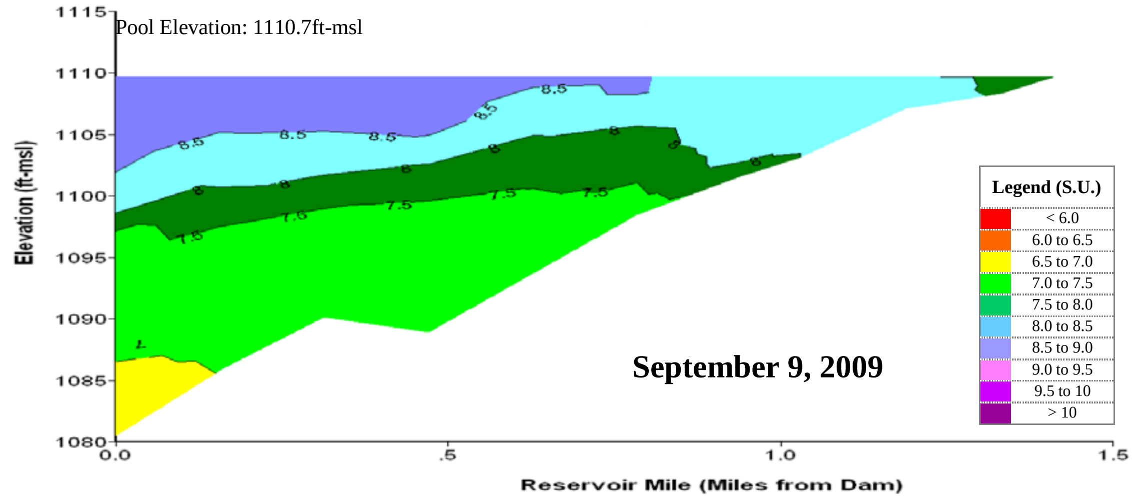


Plate 14. (Continued).

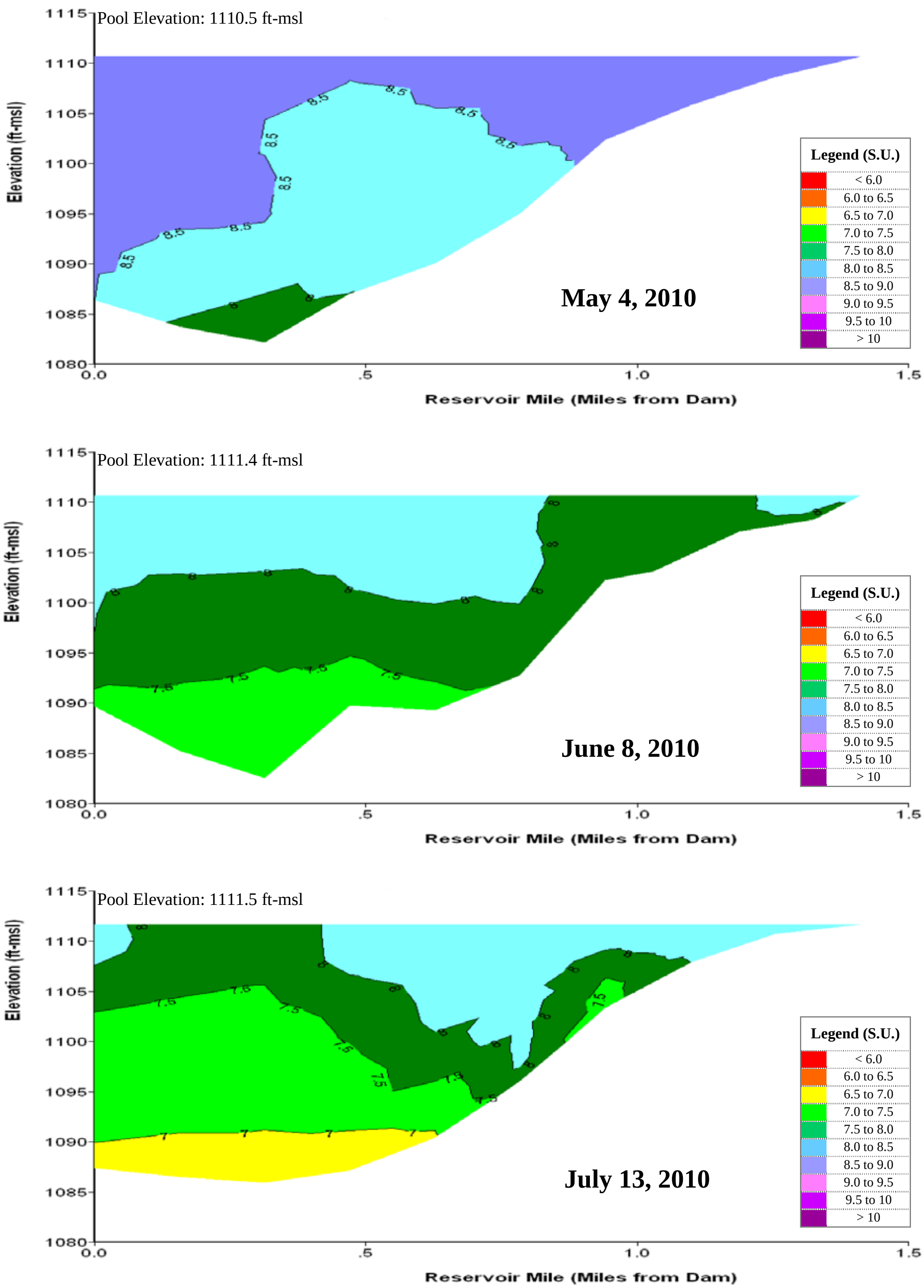
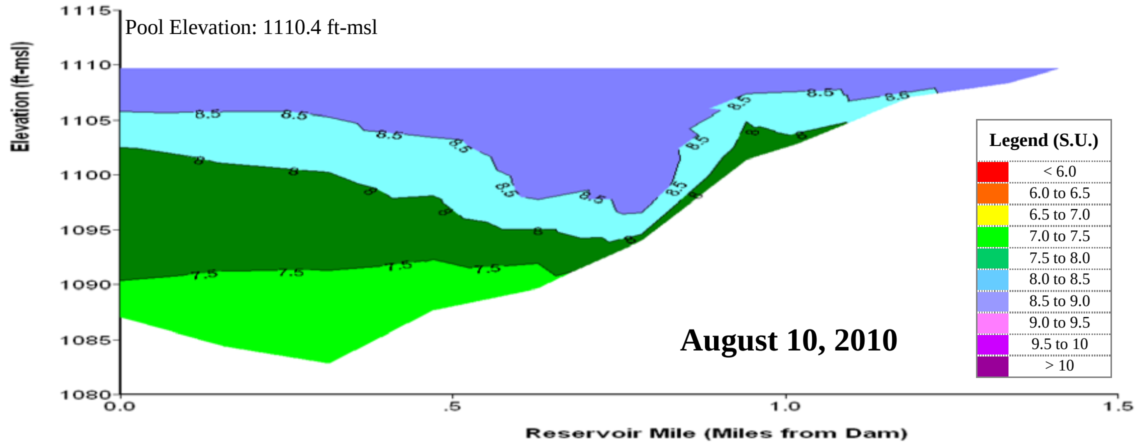


Plate 15. Longitudinal pH contour plots of Ed Zorinsky Reservoir based on depth-profile pH levels (S.U.) measured at sites EZRLKND1, EZRLKML1A, EZRLKML1B, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2010.



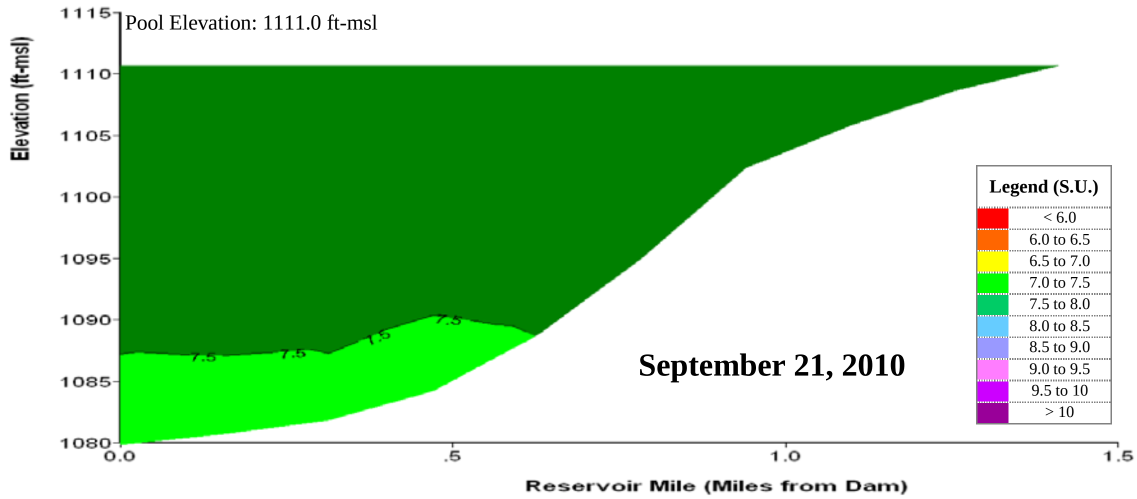


Plate 15. (Continued).

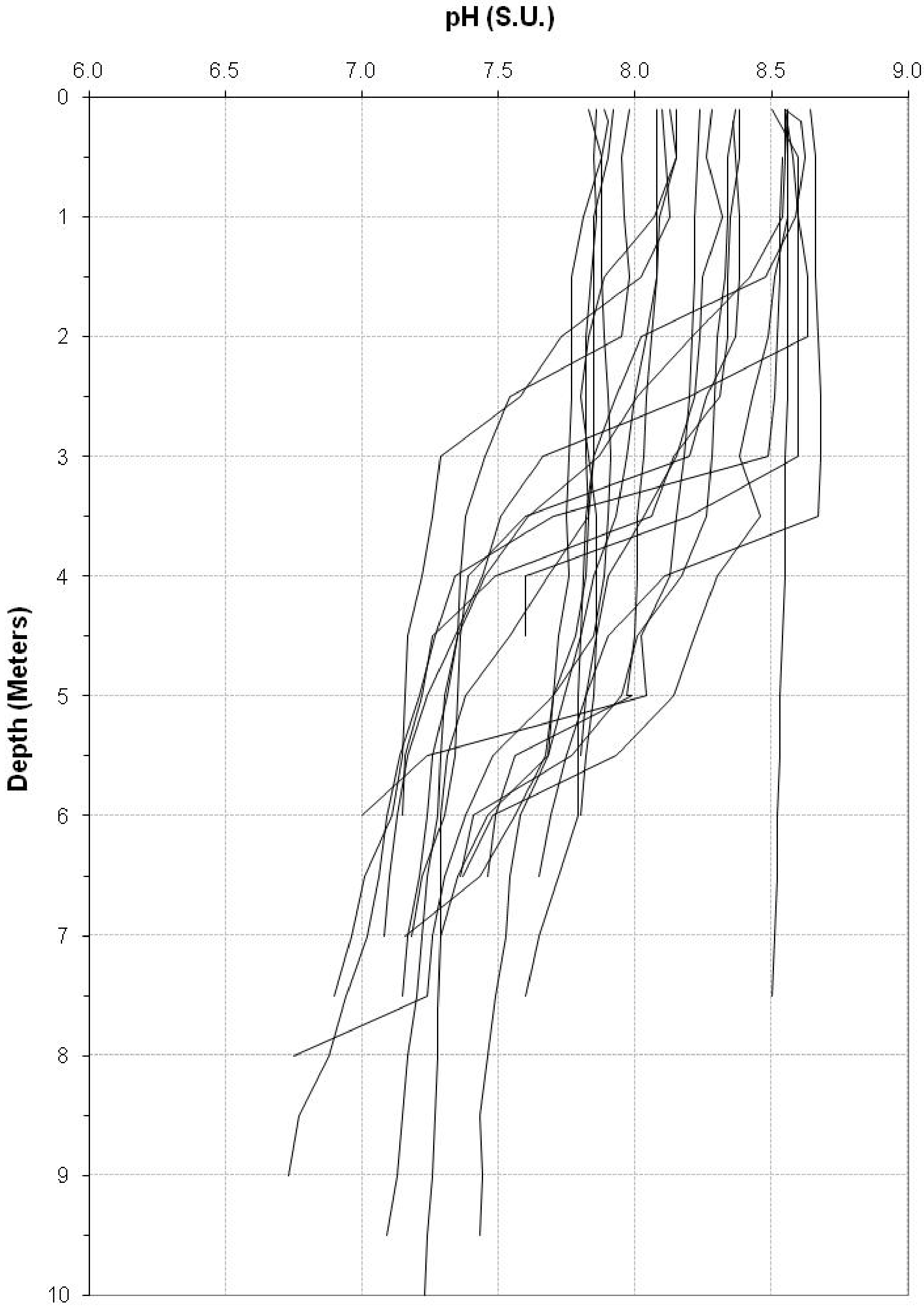


Plate 16. pH depth profiles for Ed Zorinsky Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2006 through 20010.

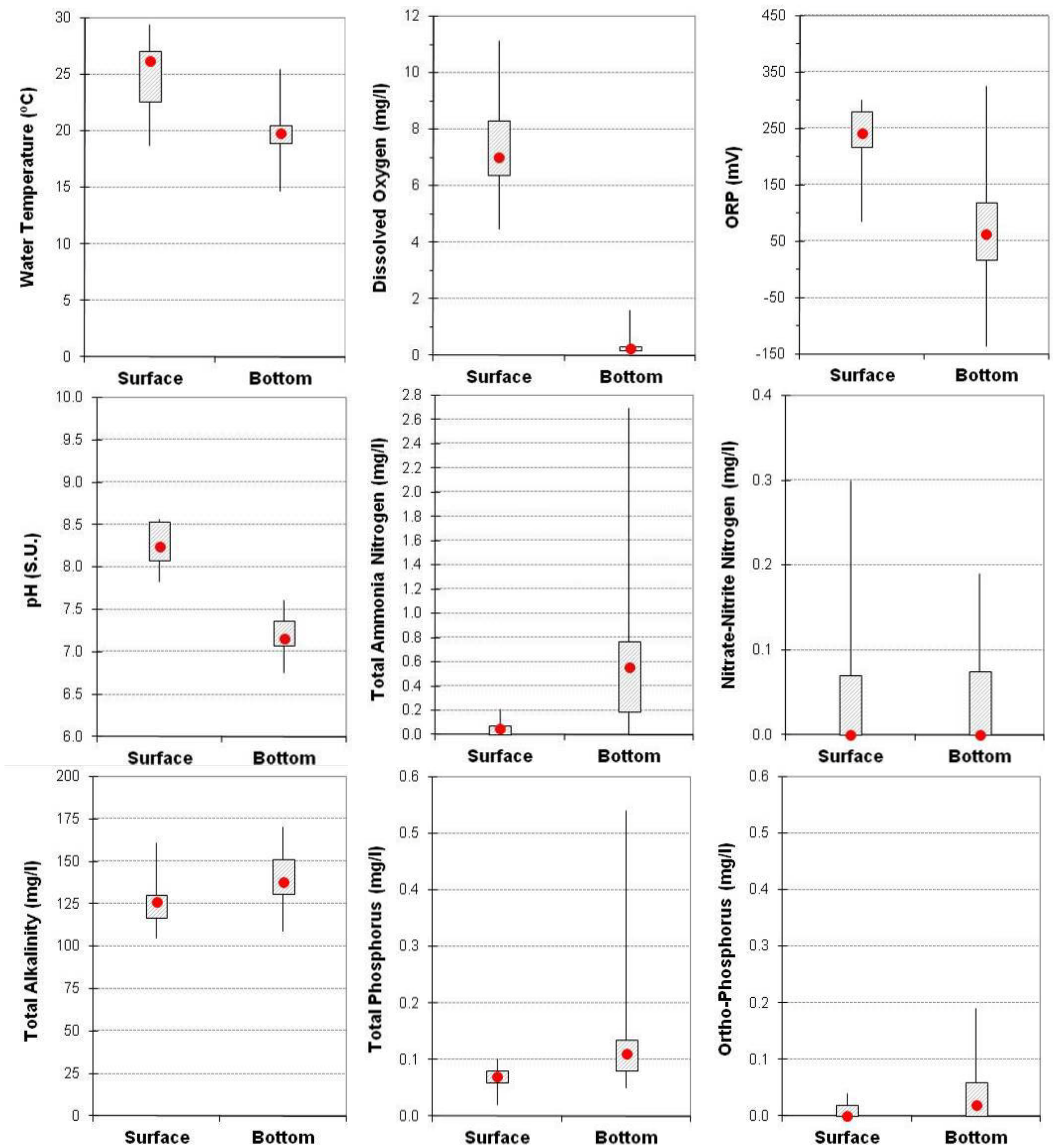


Plate 17. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, total ammonia nitrogen, nitrate-nitrite nitrogen, alkalinity, total phosphorus, and ortho-phosphorus measured in Ed Zorinsky Reservoir when summer hypoxic conditions were present during the 5-year period of 2006 through 2010. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

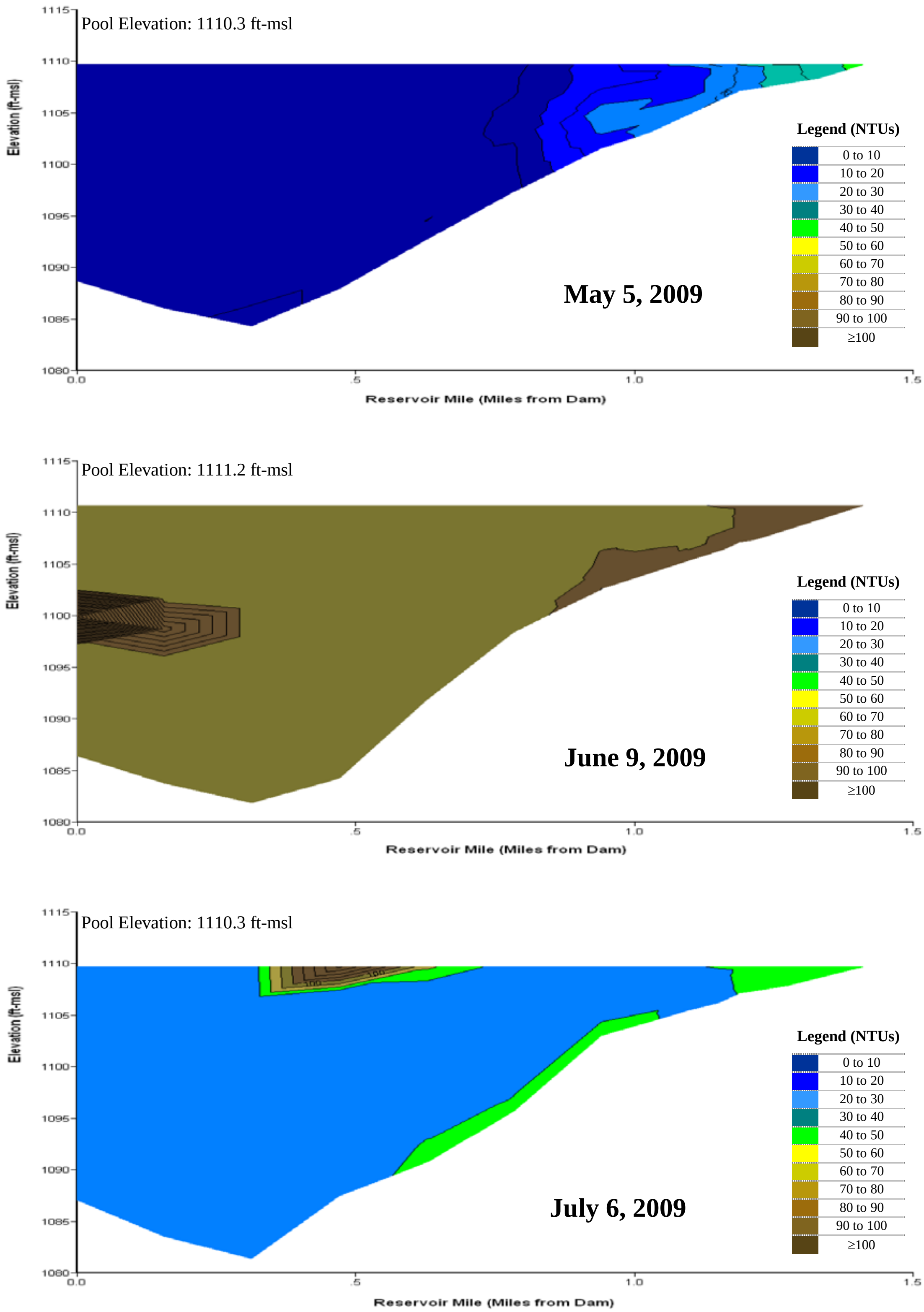
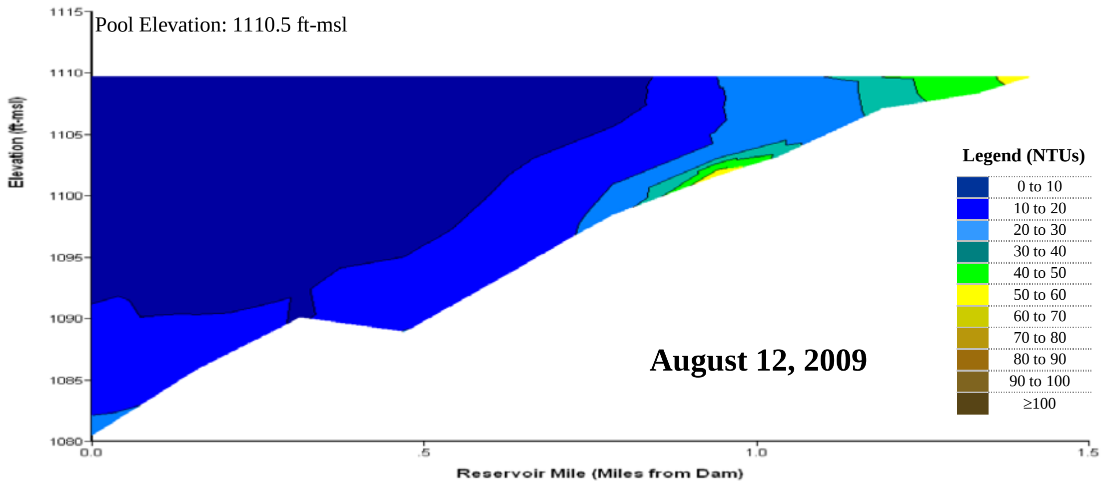


Plate 18. Longitudinal turbidity contour plots of Ed Zorinsky Reservoir based on depth-profile turbidity levels (NTU) measured from May to September 2009.



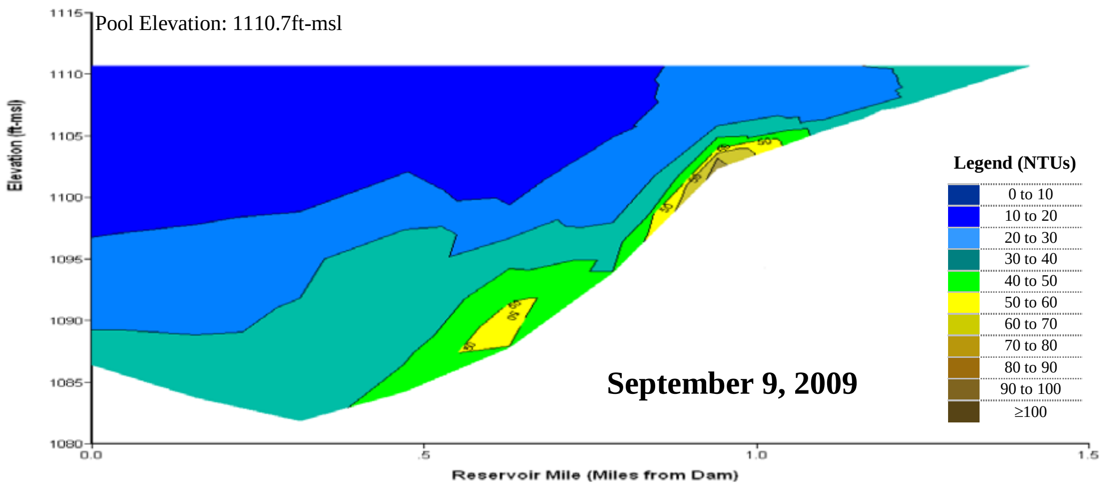


Plate 18. (Continued).

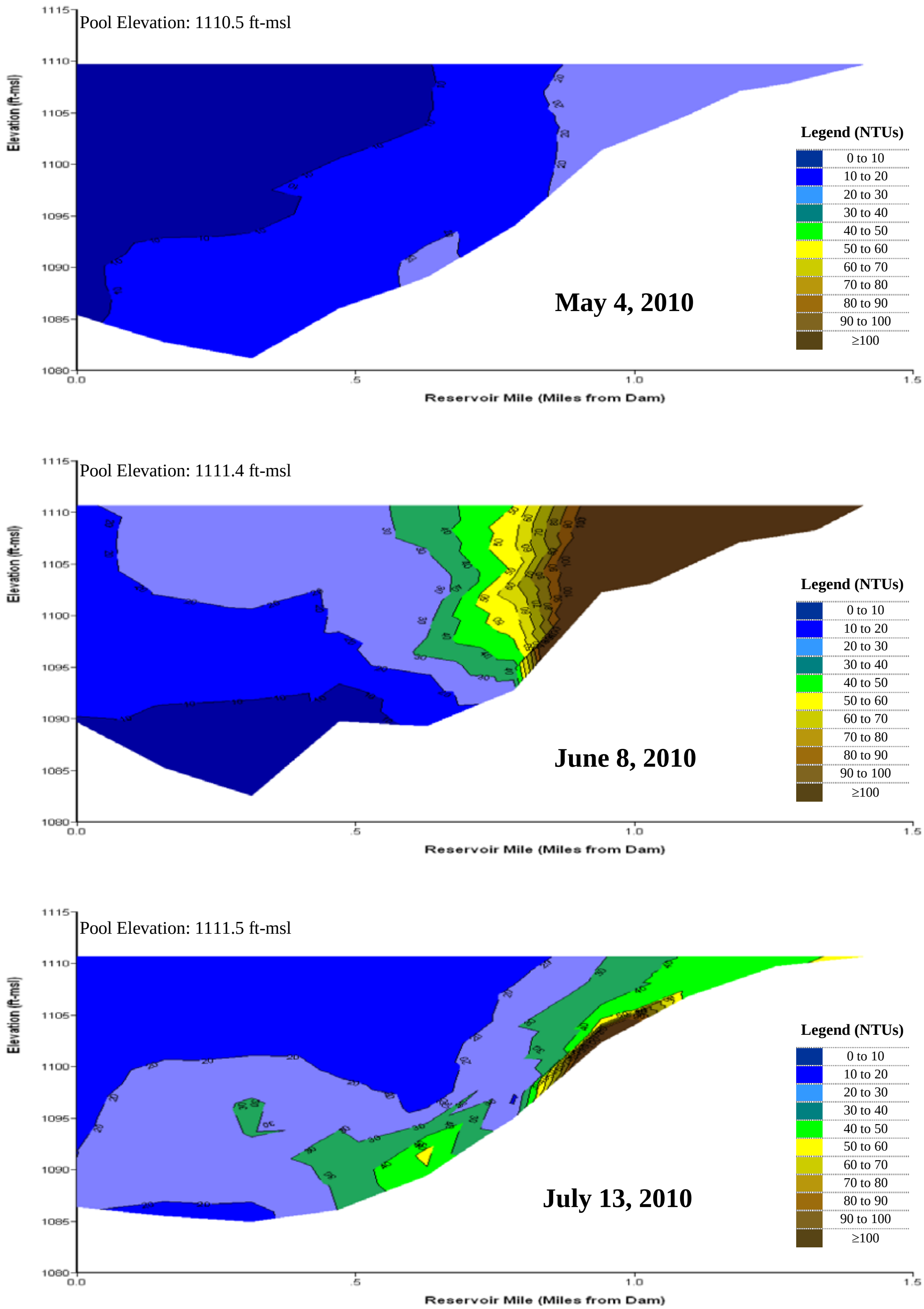
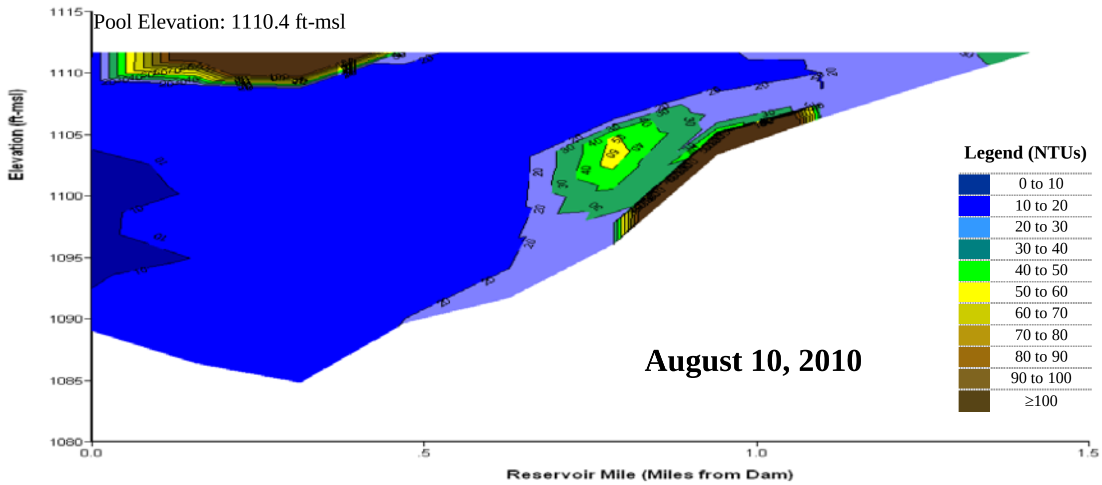


Plate 19. Longitudinal turbidity contour plots of Ed Zorinsky Reservoir based on depth-profile turbidity levels (NTU) measured at sites EZRLKND1, EZRLKML1A, EZRLKML1B, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2010.



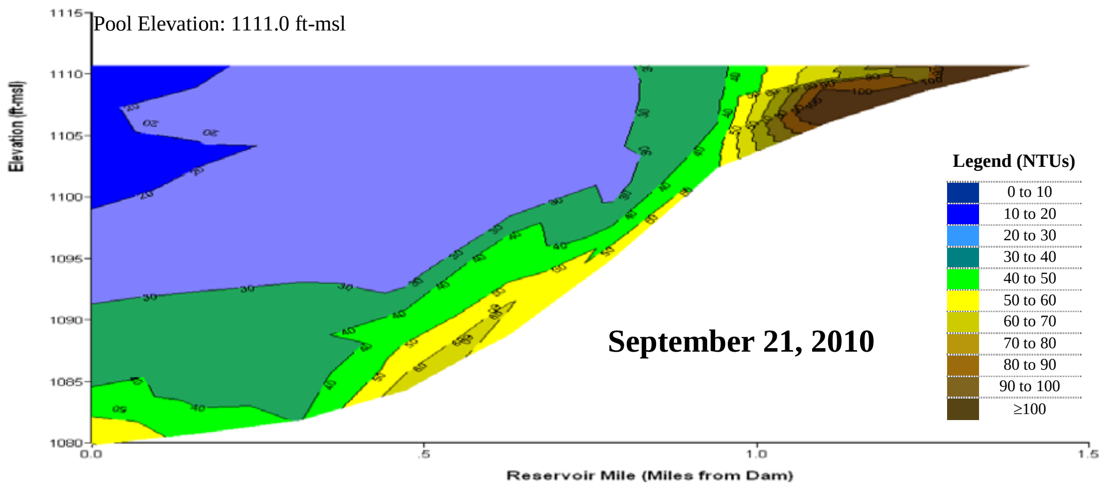


Plate 19. (Continued).

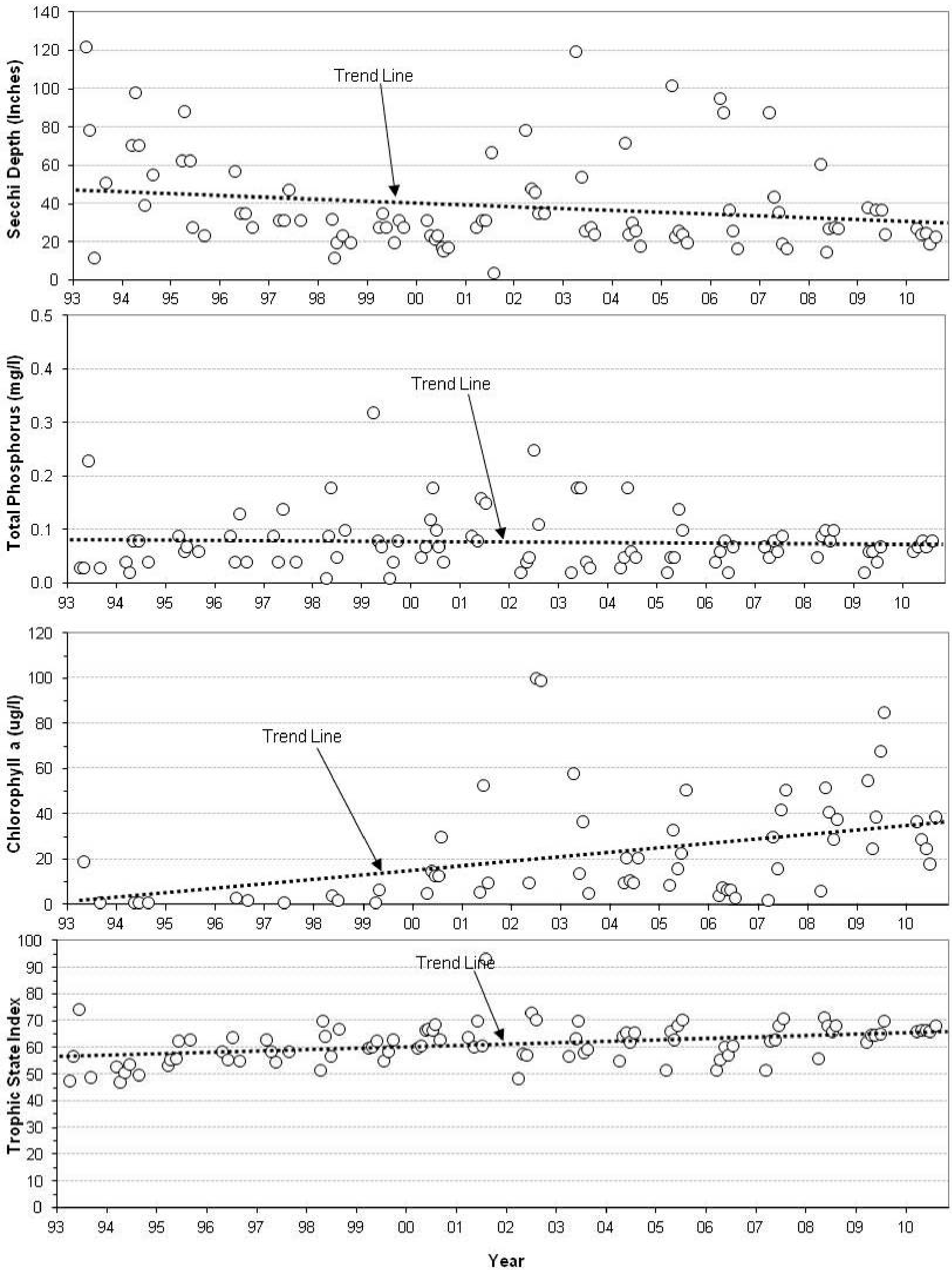


Plate 20. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Ed Zorinsky Reservoir at the near-dam, ambient site (i.e., site EZRLKND1) over the 31-year period of 1980 through 2010.

Plate 21. Summary of runoff water quality conditions monitored in the Boxelder Creek inflow to Ed Zorinsky Reservoir at monitoring site EZRNF1 during the 5-year period 2006 through 2010.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Turbidity (NTUs)	1	11	1695	872	28	5028	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	17	-----	0.19	n.d.	0.45	(1)	(1)	(1)
Kjeldahl N, Total (mg/l)	0.1	17	3.15	2.23	0.72	14.30	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	17	0.91	0.80	0.36	2.20	100(4)	0	0%
Phosphorus, Total (mg/l)	0.02	17	1.62	1.00	0.04	6.28	-----	-----	-----
Suspended Solids, Total (mg/l)	4	17	1627	1172	34	6800	-----	-----	-----
Acetochlor, Total (ug/l)(C)	0.05	10	-----	0.30	n.d.	1.80	-----	-----	-----
Alachlor, Total (ug/l)(C)	0.05	7	-----	n.d.	n.d.	0.15	760(2), 76(3)	0	0%
Atrazine, Total (ug/l)(C)	0.05	17	-----	0.30	n.d.	3.70	330(2), 12(3)	0	0%
Metolachlor, Total (ug/l)(C)	0.05	17	-----	n.d.	n.d.	0.50	390(2), 100(3)	0	0%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Total ammonia criteria pH and temperature dependent. Since pH was not measured criteria are not calculated.
(2) Acute criterion for aquatic life.
(3) Chronic criterion for aquatic life.
(4) Agricultural criteria for surface waters.
(C) Immunoassay analysis.

Plate 22. Summary of water quality conditions monitored in Glenn Cunningham Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site GCRLKND1) from May to September during the 2-year period 2009 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	9	1121.3	1121.6	1118.7	1122.4	-----	-----	-----
Water Temperature (°C)	0.1	109	22.2	22.1	15.0	30.7	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	109	5.2	6.5	0.1	11.7	≥ 5[2]	44	40%
Dissolved Oxygen (% Sat.)	0.1	109	63.1	77.1	1.2	164.2	-----	-----	-----
Specific Conductance (umho/cm)	1	109	474	483	377	598	2,000[3]	0	0%
pH (S.U.)	0.1	109	7.9	8.0	7.0	8.9	≥6.5 & ≤9.0[1]	0	0%
Turbidity (NTUs)	1	109	8	7	0	65	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	109	309	354	-124	460	-----	-----	-----
Secchi Depth (in.)	1	9	37	40	23	54	-----	-----	-----
Alkalinity, Total (mg/l)	7	18	215	214	167	260	20[1]	-----	-----
Ammonia, Total (mg/l)	0.02	18	0.26	0.16	0.02	1.14	7.9 [4,5], 1.4 [4,6]	0	0%
Chlorophyll *a* (ug/l) – Field Probe	1	109	31	29	9	123	10[7]	105	96%
Chlorophyll *a* (ug/l) – Lab Determined	1	9	31	34	13	45	10[7]	9	100%
Hardness, Total (mg/l)	0.4	2	188.50	188.50	158.00	219.00	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	18	1.1	1.1	0.6	1.9	-----	-----	-----
Nitrogen, Total (mg/)	0.1	18	1.1	1.1	0.6	1.9	1 [7]	13	72%
Nitrate-Nitrite N, Total (mg/l)	0.02	18	-----	0.05	n.d.	0.60	100[3]	0	0%
Phosphorus, Total (mg/l)	0.02	18	0.08	0.07	0.04	0.32	0.05[7]	13	72%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	18	-----	0.03	n.d.	0.21	-----	-----	-----
Suspended Solids, Total (mg/l)	4	18	9	9	n.d.	15	-----	-----	-----
Antimony, Dissolved (ug/l)	0.5	1	0.80	0.80	0.80	0.80	88[5], 30[6]	0	0%
Arsenic, Dissolved (ug/l)	3	2	4	4	4	4	340[5], 16.7[8]	0	0%
Beryllium, Dissolved (ug/l)	2	2	-----	81	n.d.	161	130[5], 5.3[6]	1,1	50%
Cadmium, Dissolved (ug/l)	2	2	-----	n.d.	n.d.	n.d.	10.9[5], 0.4[6]	0	0%
Chromium, Dissolved (ug/l)	10	2	-----	n.d.	n.d.	n.d.	995[5], 130[6]	0	0%
Copper, Dissolved (ug/l)	2	1	3	3	3	3	24.4[5], 15.4[6]	0	0%
Lead, Dissolved (ug/l)	2	2	-----	n.d.	n.d.	n.d.	127[5], 5[6]	0	0%
Mercury, Dissolved (ug/l)	0.05	2	-----	n.d.	n.d.	n.d.	1.4[5]	0	0%
Mercury, Total (ug/l)	0.05	2	-----	n.d.	n.d.	n.d.	0.77[6]	0	0%
Nickel, Dissolved (ug/l)	10	2	-----	n.d.	n.d.	n.d.	800[5], 89 [6]	0	0%
Selenium, Total (ug/l)	2	1	2	2	2	2	20[3,5], 5[6]	0	0%
Silver, Dissolved (ug/l)	10	2	-----	n.d.	n.d.	n.d.	10.3[5]	0	0%
Thallium (ug/l)	0.5	2	-----	n.d.	n.d.	n.d.	1,400[5], 6.3[8]	0	0%
Zinc, Dissolved (ug/l)	10	2	-----	n.d.	n.d.	n.d.	200[5,6]	0	0%
Microcystin, Total (ug/l)	0.05	9	-----	n.d.	n.d.	n.d.	20[9]	0	0%
Acetochlor, Total (ug/l)[C]	0.08	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Alachlor, Total (ug/l)[C]	0.07	1	-----	n.d.	n.d.	n.d.	760[5], 76[6]	0	0%
Atrazine, Total (ug/l)[C]	0.05	1	-----	n.d.	n.d.	n.d.	330[5], 12[6]	0	0%
Metolachlor, Total (ug/l)[C]	0.13	1	-----	n.d.	n.d.	n.d.	390[5], 100[6]	0	0%
Pesticide Scan (ug/l)[D]	0.05						-----	-----	-----
Acetochlor		5	-----	n.d.	n.d.	0.40	-----	-----	-----
Atrazine		9	-----	0.20	n.d.	1.60	330[5], 12[6]	0	0%

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 23. Summary of water quality conditions monitored in Glenn Cunningham Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site GCRLKML1) from May to September during the 2-year period 2009 through 2010. [Note: Except for pool elevation and Secchi depth, results are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A,C)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	8	1121.2	1121.6	1118.7	1122.4	-----	-----	-----
Water Temperature (°C)	0.1	68	23.1	23.3	16.0	30.5	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	68	6.8	7.4	0.3	11.4	≥ 5(2)	17	25%
Dissolved Oxygen (% Sat.)	0.1	68	83.3	86.6	3.8	158.9	-----	-----	-----
Specific Conductance (umho/cm)	1	68	461	467	377	530	2,000(3)	0	0%
pH (S.U.)	0.1	68	8.1	8.1	7.4	8.9	≥6.5 & ≤9.0(1)	0	0%
Turbidity (NTUs)	1	68	14	12	2	51	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	68	357	389	89	439	-----	-----	-----
Secchi Depth (in.)	1	9	30	31	22	39	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	68	49	41	14	209	10(4)	68	100%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).
(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 24. Summary of water quality conditions monitored in Glenn Cunningham Reservoir at the up-lake ambient monitoring location (i.e., site GCRLKUP1) from May to September during the 2-year period 2009 through 2010. [Note: Except for pool elevation and Secchi depth, results are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A,C)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	8	1121.2	1121.6	1118.7	1122.4	-----	-----	-----
Water Temperature (°C)	0.1	21	23.0	23.5	16.6	28.9	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	21	7.8	7.5	4.8	11.5	≥ 5(2)	1	5%
Dissolved Oxygen (% Sat.)	0.1	21	95.2	93.5	57.8	137.5	-----	-----	-----
Specific Conductance (umho/cm)	1	21	458	469	392	532	2,000(3)	0	0%
pH (S.U.)	0.1	21	8.1	8.1	7.5	8.6	≥6.5 & ≤9.0(1)	0	0%
Turbidity (NTUs)	1	21	26	29	11	44	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	21	350	353	167	427	-----	-----	-----
Secchi Depth (in.)	1	9	20	19	15	26	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	21	40	40	14	139	10(4)	21	100%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).
(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

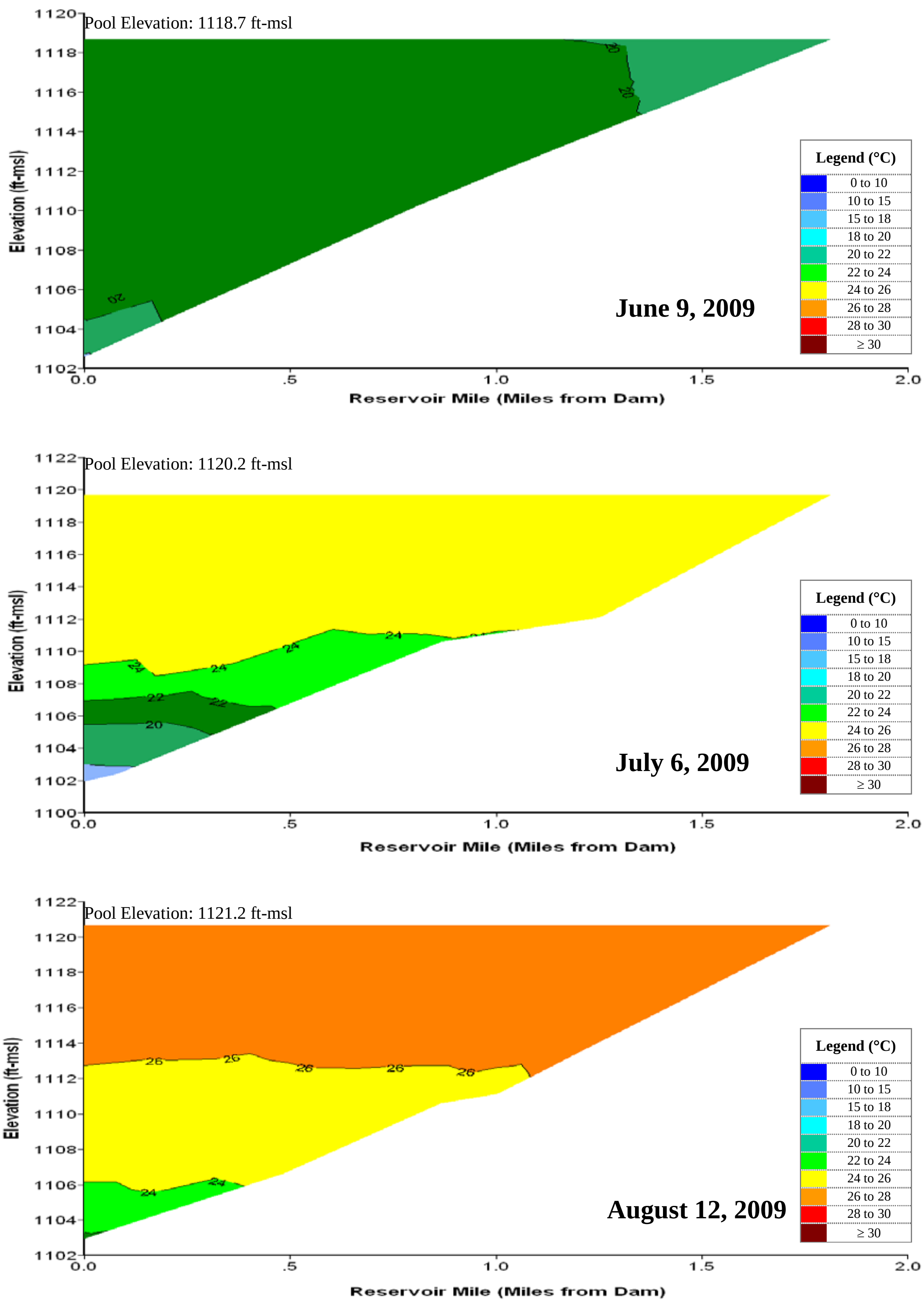


Plate 25. Longitudinal water temperature contour plots of Cunningham Reservoir based on depth-profile water temperatures (°C) measured from June to September 2009.

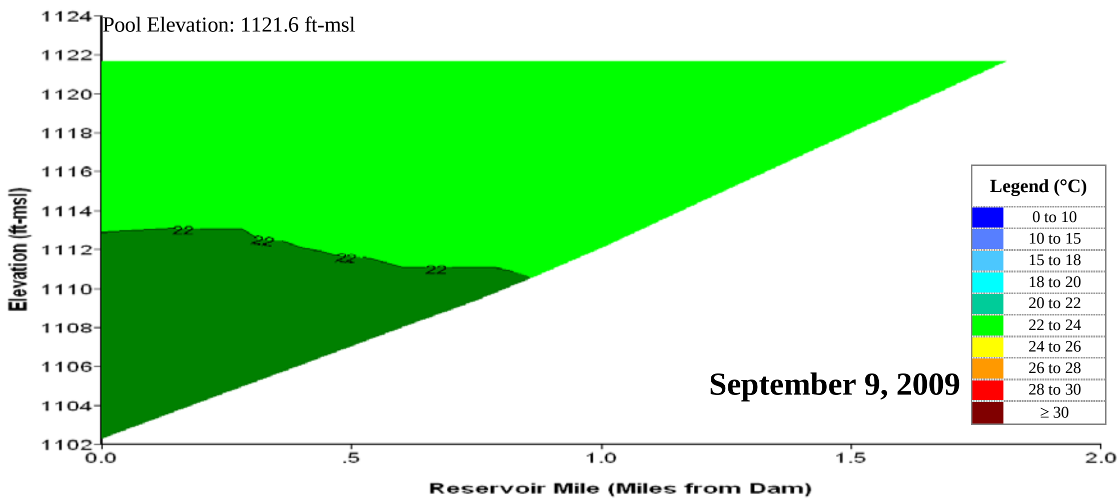


Plate 25. (Continued)

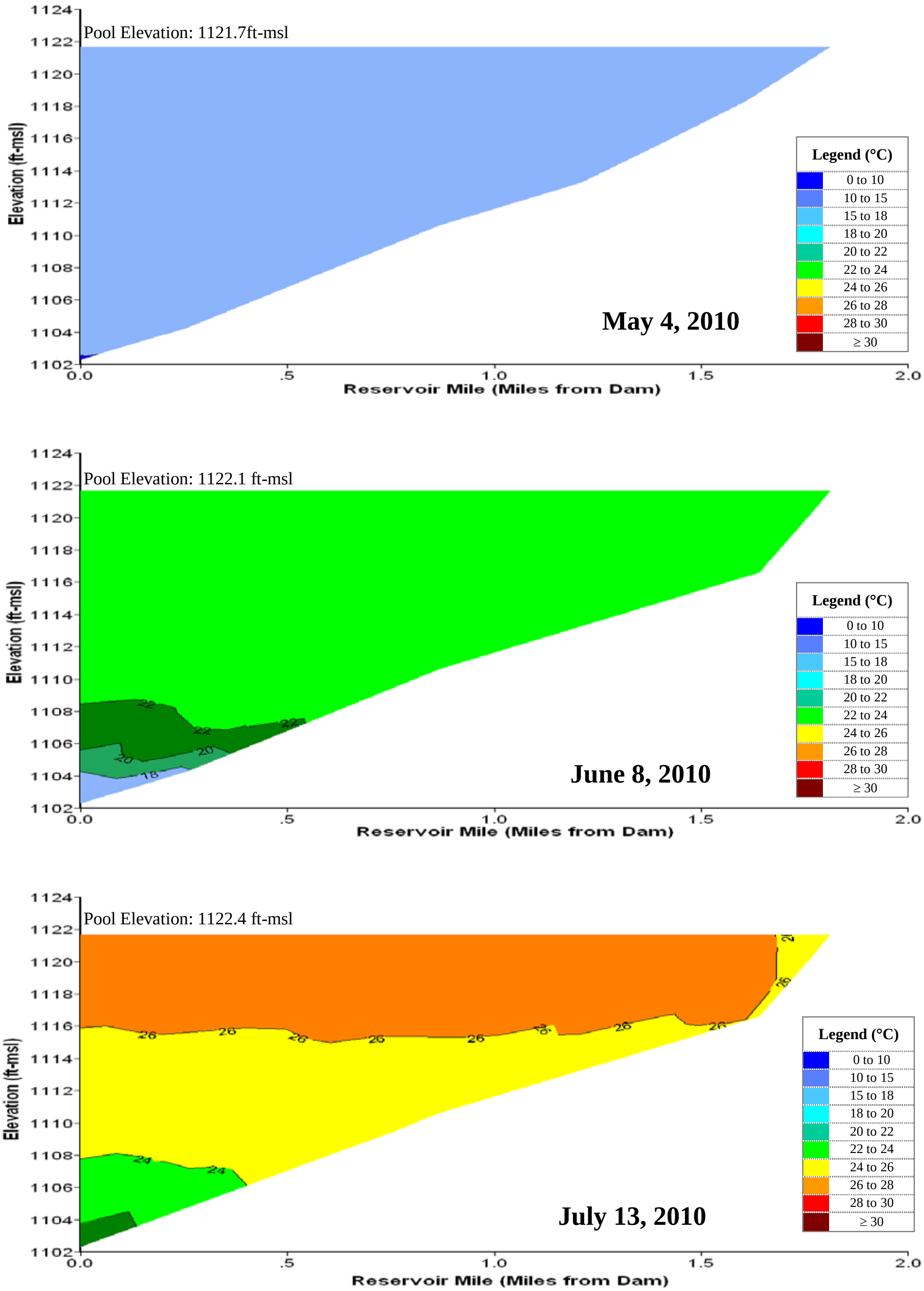
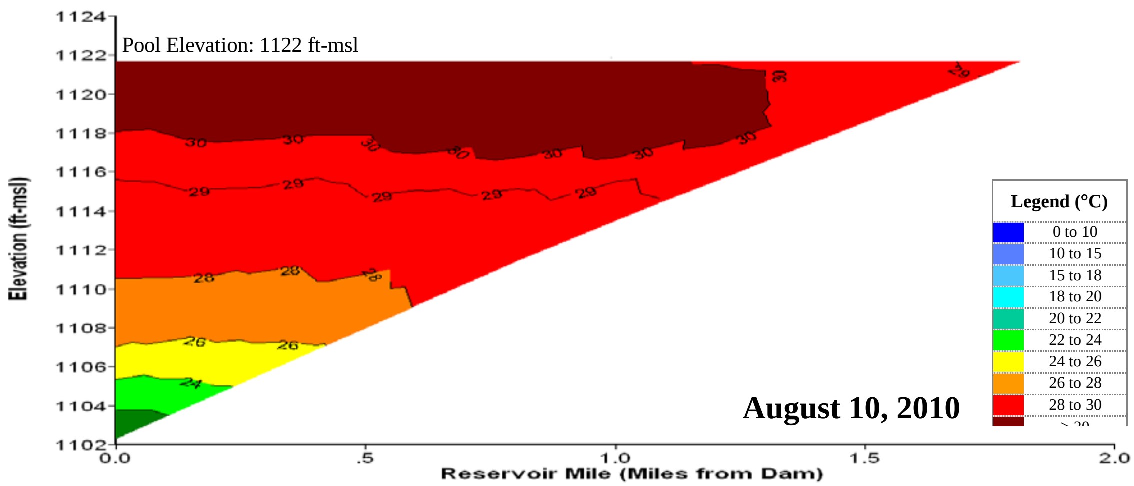


Plate 26. Longitudinal water temperature contour plots of Cunningham Reservoir based on depth-profile water temperatures (°C) measured from May to September 2010.



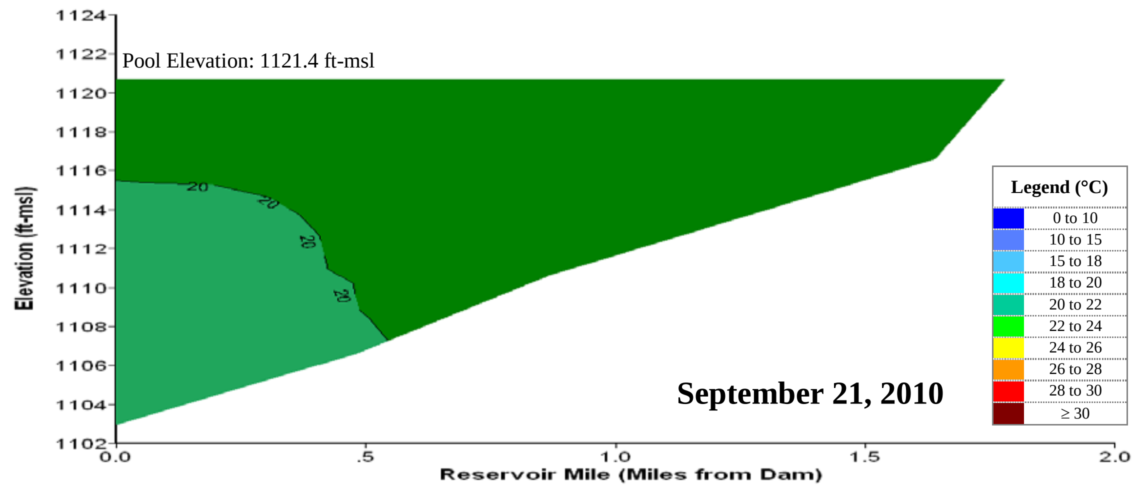


Plate 26. (Continued)

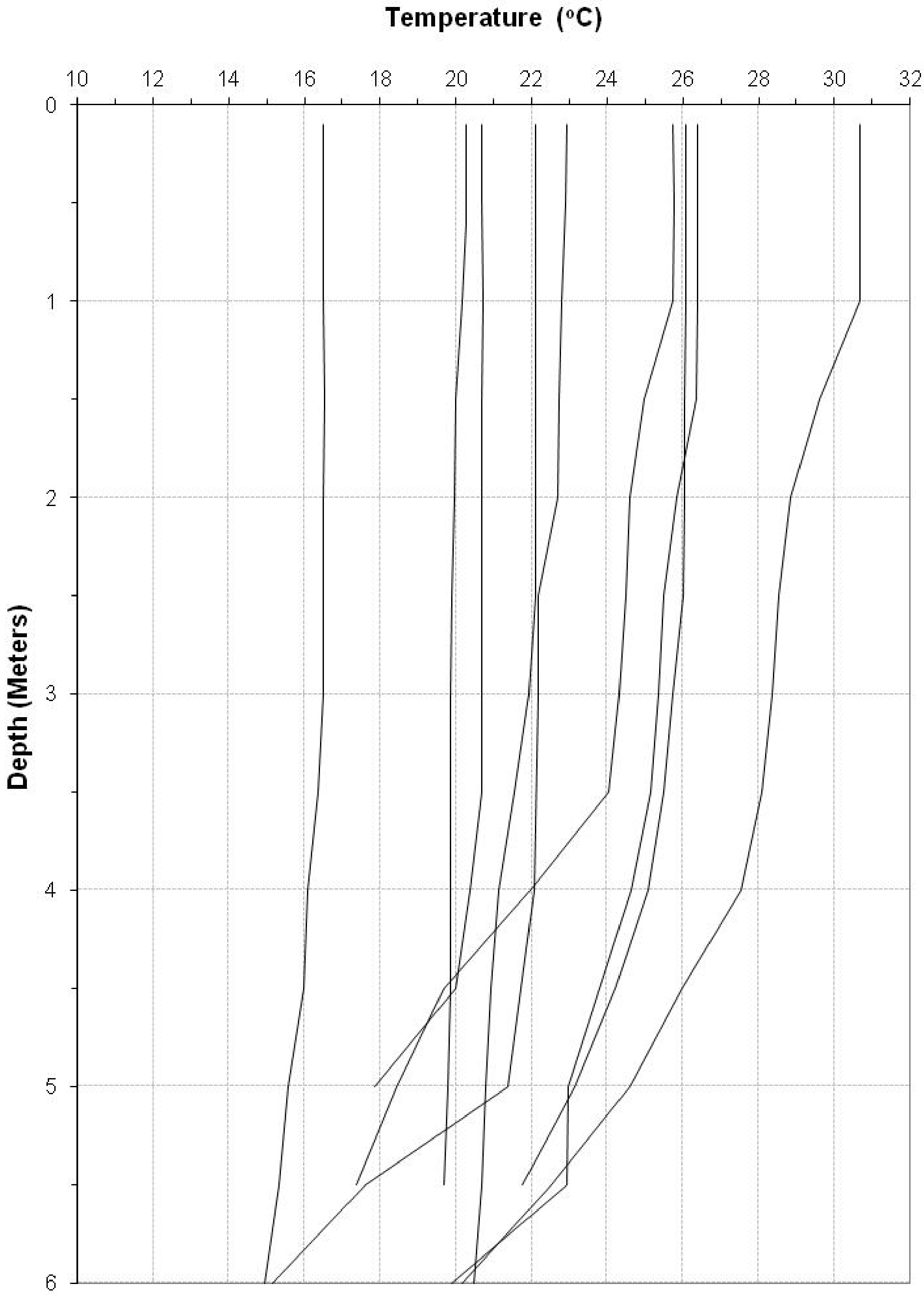


Plate 27. Temperature depth profiles for Glen Cunningham Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., GCRLKND1) during the summer over the 2-year period of 2009 through 2010.

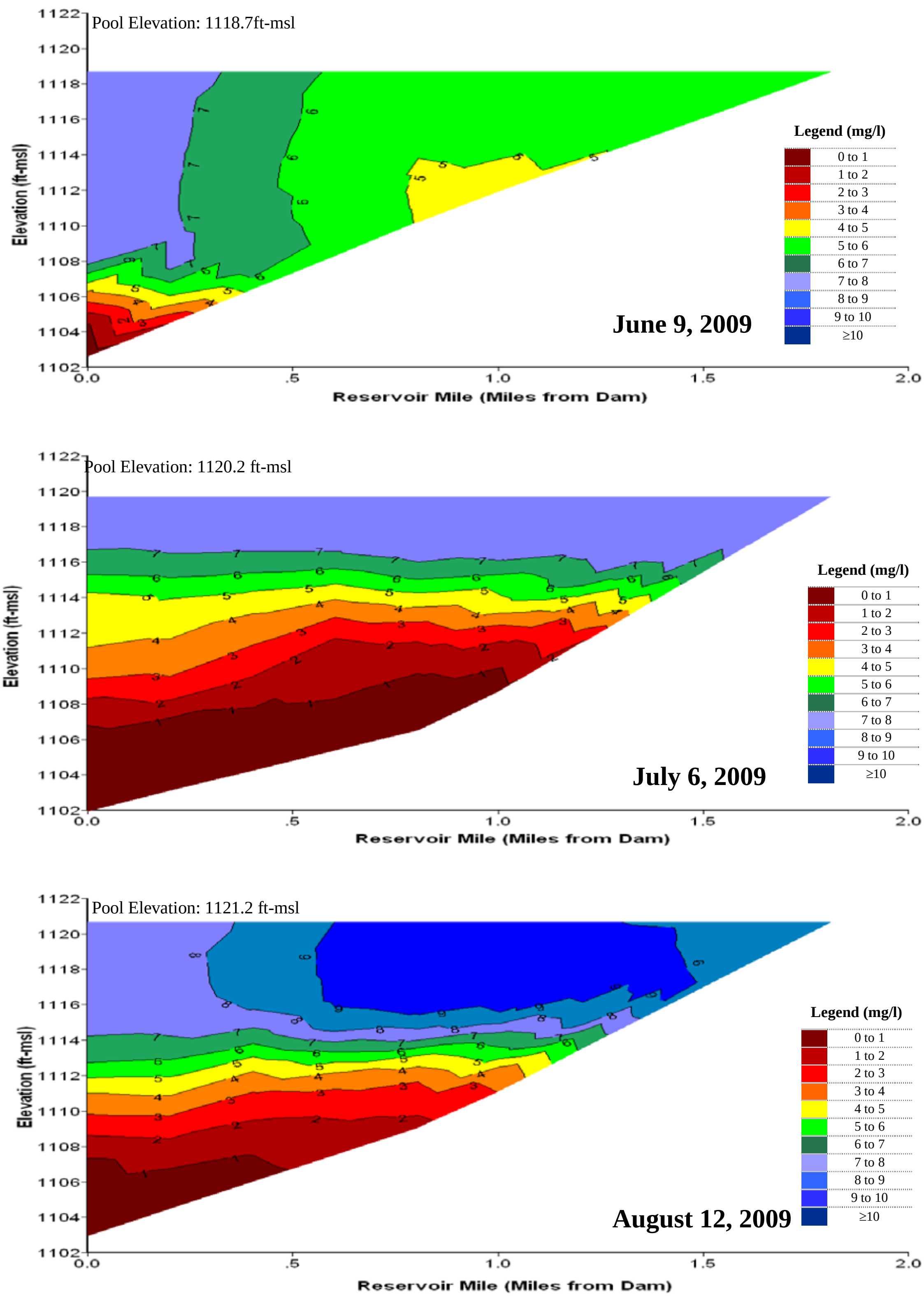


Plate 28. Longitudinal dissolved oxygen contour plots of Cunningham Reservoir based on depth-profile water temperatures (°C) measured from June to September in 2009.

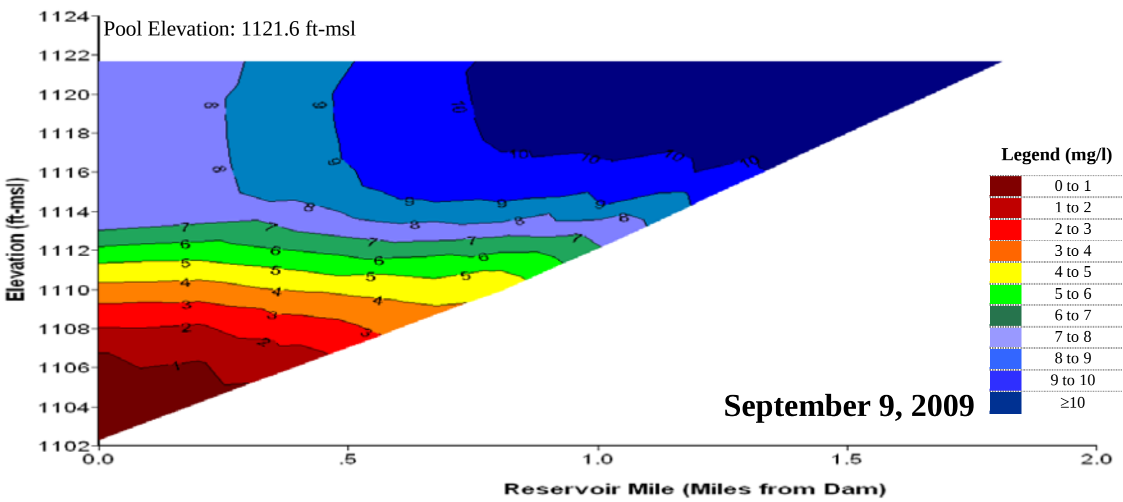


Plate 28. (Continued)

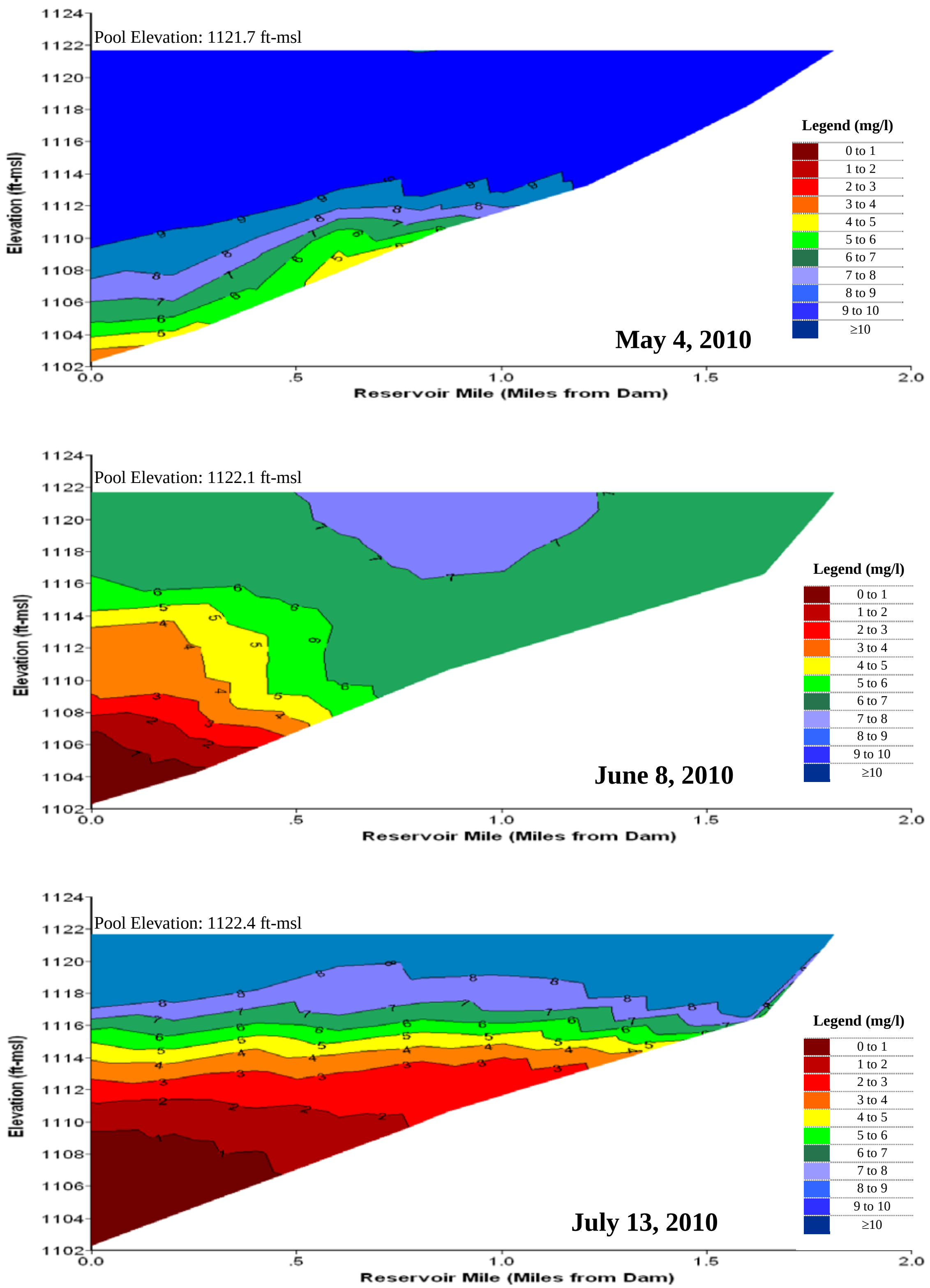
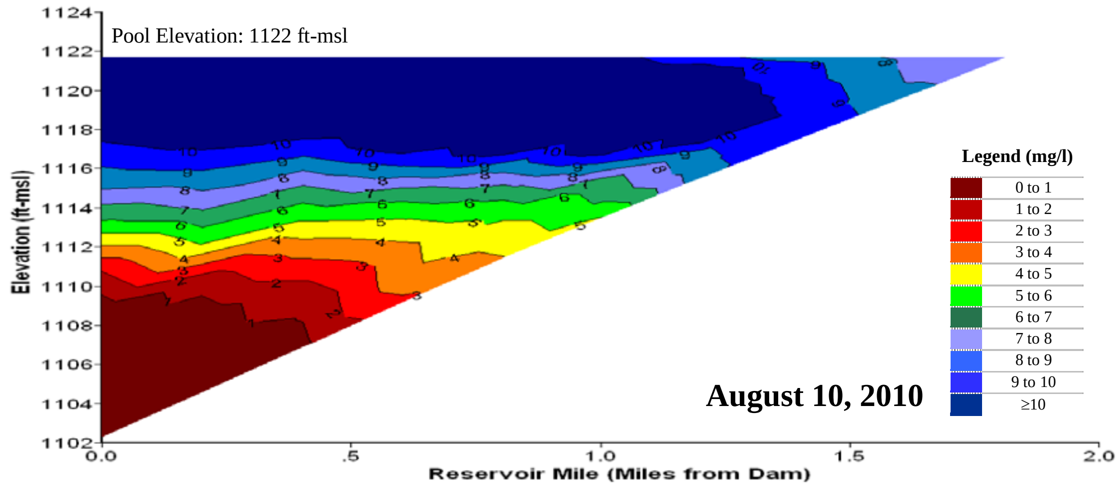


Plate 29. Longitudinal dissolved oxygen contour plots of Cunningham Reservoir based on depth-profile water temperatures (°C) measured from May to September in 2010.



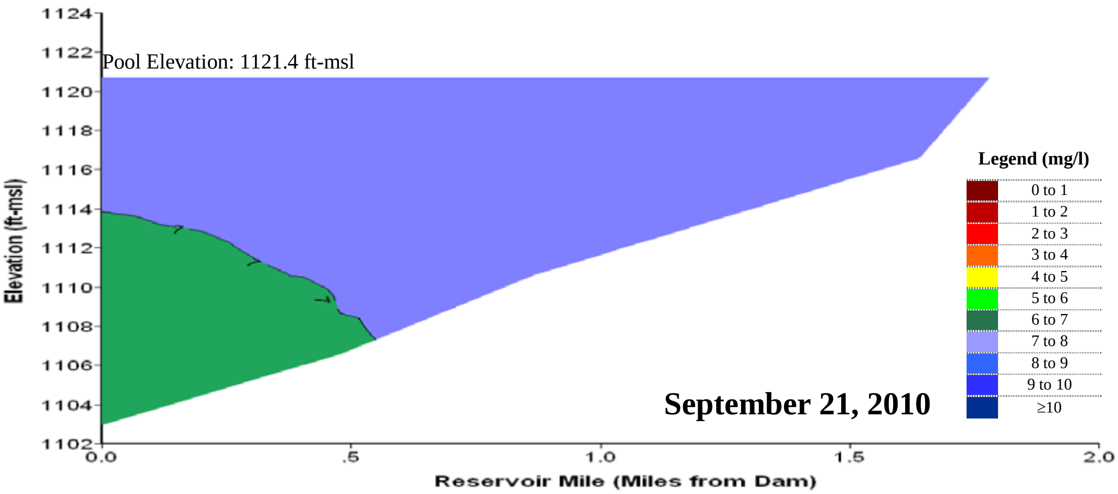


Plate 29. (Continued)

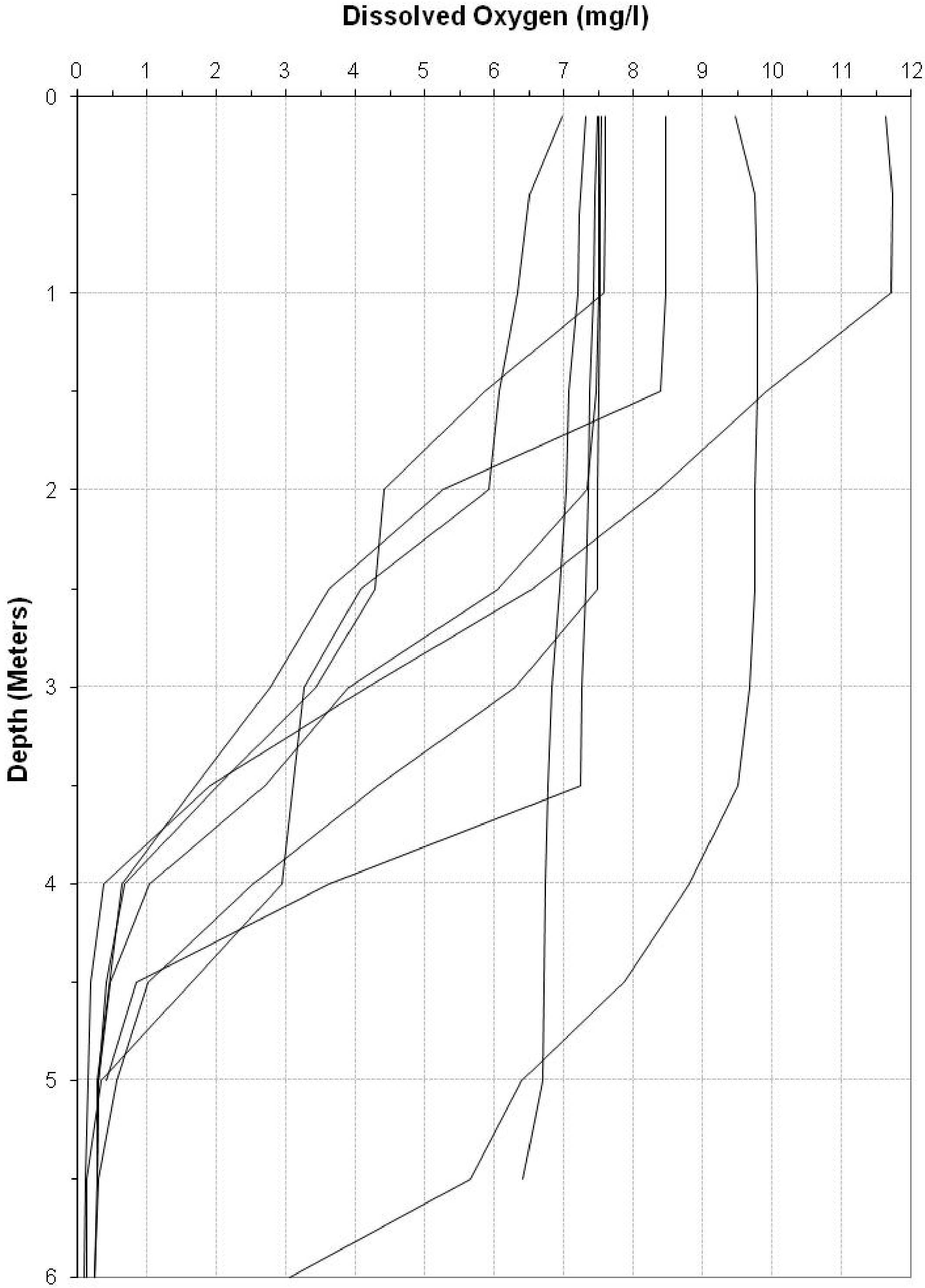


Plate 30. Dissolved oxygen depth profiles for Glen Cunningham Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., GCRLKND1) during the summer over the 2-year period of 2009 through 2010.

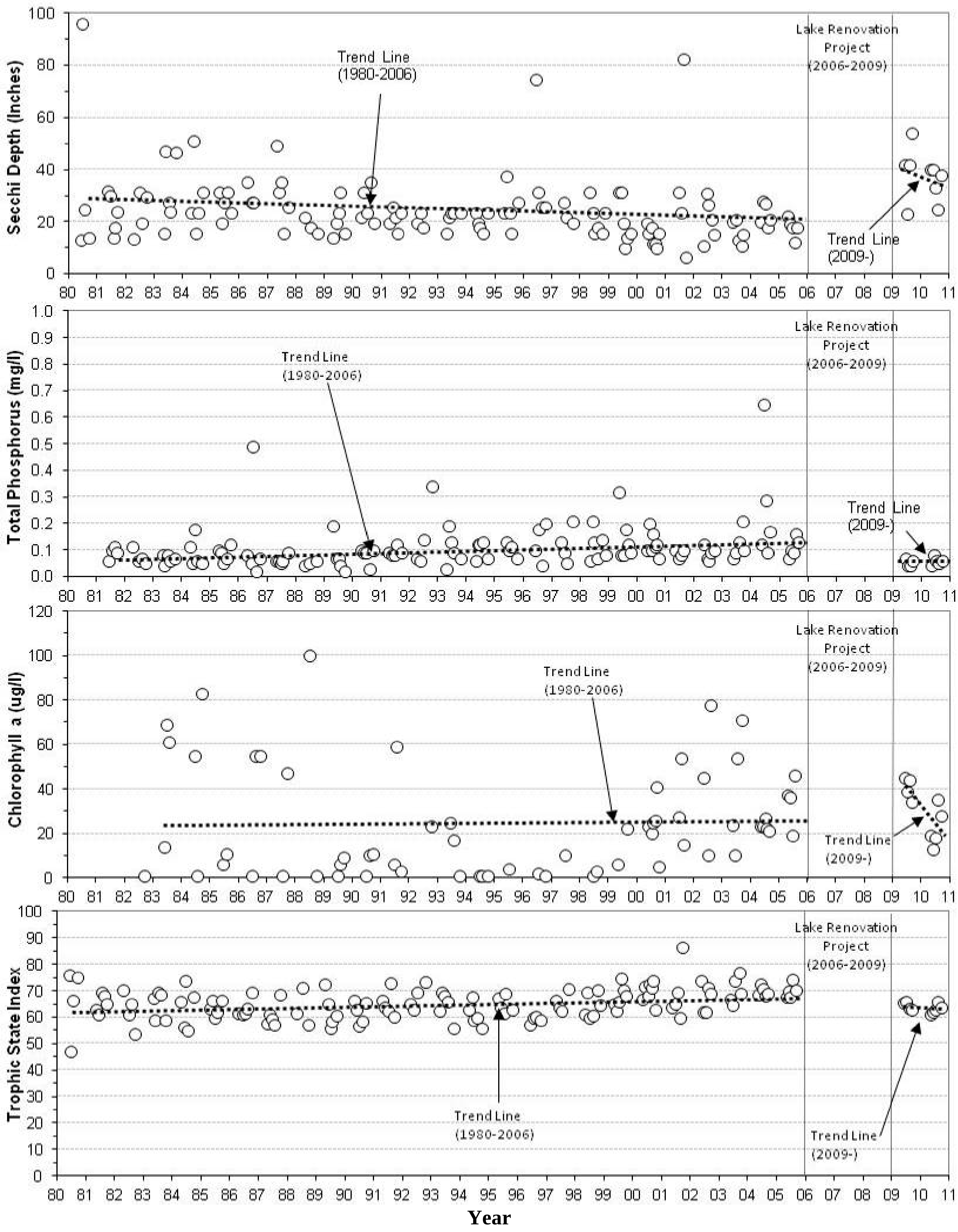


Plate 31. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Glenn Cunningham Reservoir at the near-dam, ambient site (i.e., site GCRLKND1) over the 31-year period of 1980 to 2010.

Plate 32. Summary of runoff water quality conditions monitored in the Knight Creek inflow to Glenn Cunningham Reservoir at monitoring site GCRNFNRT1 during the period 2006 through 2010.

	Monitoring Results						**Water Quality Standards Attainment**		
Parameter	**Detection Limit**	**No. of Obs.**	**Mean**[A]	**Median**	**Min.**	**Max.**	**State WQS Criteria**[B]	**No. of WQS Exceedences**	**Percent WQS Exceedence**
Turbidity (NTUs)	1	9	1815	239	10	11012	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	11	-----	0.49	n.d.	1.86	[1]	[1]	[1]
Kjeldahl N, Total (mg/l)	0.1	11	8.5	4.7	0.6	23.0	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	11	5.18	4.9	1.5	10.4	100[4]	0	0%
Phosphorus, Total (mg/l)	0.02	11	2.50	0.98	0.03	10	-----	-----	-----
Suspended Solids, Total (mg/l)	4	11	1977	370	39	9930	-----	-----	-----
Acetochlor, Total (ug/l)[C]	0.05	7	-----	n.d.	n.d.	1.4	-----	-----	-----
Alachlor, Total (ug/l)[C]	0.05	4	-----	0.05	n.d.	0.12	760[2], 76[3]	0	0%
Atrazine, Total (ug/l)[C]	0.05	11	-----	0.4	n.d.	28	330[2], 12[3]	0,1	9%
Metolachlor, Total (ug/l)[C]	0.05	11	-----	n.d.	n.d.	1.4	390[2], 100[3]	0	0%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Total ammonia criteria pH and temperature dependent. Since pH was not measured criteria are not calculated.
(2) Acute criterion for aquatic life.
(3) Chronic criterion for aquatic life.
(4) Agricultural criteria for surface waters.
(C) Immunoassay analysis.

Plate 33. Summary of runoff water quality conditions monitored in the east unnamed tributary inflow to Glenn Cunningham Reservoir at monitoring site GCRNFEST1 during the period 2006 through 2010.

	Monitoring Results						**Water Quality Standards Attainment**		
Parameter	**Detection Limit**	**No. of Obs.**	**Mean**[A]	**Median**	**Min.**	**Max.**	**State WQS Criteria**[B]	**No. of WQS Exceedences**	**Percent WQS Exceedence**
Turbidity (NTUs)	1	9	411	61	6	1750	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	10	-----	0.12	n.d.	0.28	[1]	[1]	[1]
Kjeldahl N, Total (mg/l)	0.1	10	2.2	1.1	0.7	4.9	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	10	0.69	0.75	0.17	1.20	100[4]	0	0%
Phosphorus, Total (mg/l)	0.02	10	0.60	0.43	0.03	1.80	-----	-----	-----
Suspended Solids, Total (mg/l)	4	10	574	207	13	3470	-----	-----	-----
Acetochlor, Total (ug/l)[C]	0.05	7	-----	n.d.	n.d.	2.20	-----	-----	-----
Alachlor, Total (ug/l)[C]	0.05	3	-----	n.d.	n.d.	0.08	760[2], 76[3]	0	0%
Atrazine, Total (ug/l)[C]	0.05	10	-----	n.d.	n.d.	0.31	330[2], 12[3]	0	0%
Metolachlor, Total (ug/l)[C]	0.05	10	-----	n.d.	n.d.	0.40	390[2], 100[3]	0	0%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Total ammonia criteria pH and temperature dependent. Since pH was not measured criteria are not calculated.
(2) Acute criterion for aquatic life.
(3) Chronic criterion for aquatic life.
(4) Agricultural criteria for surface waters.
(C) Immunoassay analysis.

Plate 34. Summary of runoff water quality conditions monitored in the east unnamed tributary inflow to Glenn Cunningham Reservoir at monitoring site GCRNFNRT2 during 2009**.**

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	**No. of Obs.**	**Mean**(A)	**Median**	**Min.**	**Max.**	**State WQS Criteria**(B)	**No. of WQS Exceedences**	**Percent WQS Exceedence**
Turbidity (NTUs)	1	4	702	390	8	2018	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	4	0.52	0.43	0.11	1.12	(1)	(1)	(1)
Kjeldahl N, Total (mg/l)	0.1	4	2.6	2.7	0.8	4.3	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	4	2.75	3.00	1.70	3.30	100(4)	0	0%
Phosphorus, Total (mg/l)	0.02	4	0.98	0.91	0.09	2.02	-----	-----	-----
Suspended Solids, Total (mg/l)	4	4	605	590	6	1233	-----	-----	-----
Acetochlor, Total (ug/l)(C)	0.05	4	-----	n.d.	n.d.	0.20	-----	-----	-----
Atrazine, Total (ug/l)(C)	0.05	4	-----	n.d.	n.d.	0.20	330(2), 12(3)	0	0%
Metolachlor, Total (ug/l)(C)	0.05	4	-----	n.d.	n.d.	0.40	390(2), 100(3)	0	0%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Total ammonia criteria pH and temperature dependent. Since pH was not measured criteria are not calculated.
(2) Acute criterion for aquatic life.
(3) Chronic criterion for aquatic life.
(4) Agricultural criteria for surface waters.
(C) Immunoassay analysis.

Plate 35. Summary of water quality conditions monitored in Standing Bear Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site STBLKND1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	25	1104.3	1104.3	1102.8	1105.3	-----	-----	-----
Water Temperature (°C)	0.1	303	21.8	21.7	12.7	29.6	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	303	5.5	6.7	0.1	11.3	≥ 5(2)	115	38%
Dissolved Oxygen (% Sat.)	0.1	279	64.6	76.2	1.1	144.2	-----	-----	-----
Specific Conductance (umho/cm)	1	291	407	394	232	687	2,000(3)	0	0%
pH (S.U.)	0.1	280	8.0	8.1	6.6	9.2	≥6.5 & ≤9.0(1)	0, 2	0, 1%
Turbidity (NTUs)	1	279	15	13	0	48	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	291	224	244	-139	429	-----	-----	-----
Secchi Depth (in.)	1	25	32	28	15	84	-----	-----	-----
Alkalinity, Total (mg/l)	7	50	115	110	82	168	20(1)	0	0%
Ammonia, Total (mg/l)	0.01	49	-----	0.17	0.00	6.06	6.55 (4,5), 1.26 (4,6)	0, 2	0%, 10%
Chlorophyll *a* (ug/l) – Field Probe	1	238	21	10	n.d.	126	10(7)	119	50%
Chlorophyll *a* (ug/l) – Lab Determined	1	26	40	37	n.d.	98	10(7)	18	69%
Hardness, Total (mg/l)	0.4	5	96.0	96.0	78.0	113.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	50	1.6	1.4	n.d.	7.0	-----	-----	-----
Nitrogen, Total (mg/)	0.02	50	1.60	1.4	n.d.	7.0	1 (7)	34	68%
Nitrate-Nitrite N, Total (mg/l)	0.02	36	-----	0.00	n.d.	0.16	100(3)	0	0%
Phosphorus, Total (mg/l)	0.02	50	0.13	0.09	n.d.	1.04	0.05(7)	35	70%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	49	-----	0.02	n.d.	0.19	-----	-----	-----
Suspended Solids, Total (mg/l)	4	49	10	10	n.d.	25	-----	-----	-----
Aluminum, Dissolved (ug/l)	25	5	-----	n.d.	n.d.	n.d.	750(5), 87(6)	0	0%
Antimony, Dissolved (ug/l)	0.5	5	-----	0.60	0.00	1.00	88(5), 30(6)	0	0%
Arsenic, Dissolved (ug/l)	2	5	6	6	5	8	340(5), 16.7(8)	0	0%
Beryllium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	130(5), 5.3(6)	0	0%
Cadmium, Dissolved (ug/l)	0.2	5	-----	n.d.	n.d.	n.d.	5.7(5), 0.24(6)	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	572.6(5), 74.5(6)	0	0%
Copper, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	12.9(5), 8.7(6)	0	0%
Lead, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	61.8(5), 2.4(6)	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4(5)	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	19.00	0.77(6)	1	20%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	452.3(5), 50.2(6)	0	0%
Selenium, Total (ug/l)	1	5	-----	n.d.	n.d.	1	20(3,5), 5(6)	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	3.2(5)	0	0%
Thallium (ug/l)	6	5	-----	n.d.	n.d.	n.d.	1,400(5), 6.3(8)	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	16	113.2(5,6)	0	0%
Microcystin, Total (ug/l)	0.05	25	-----	n.d.	n.d.	0.83	20(9)	0	0%
Acetochlor, Total (ug/l)(C)	0.08	5	-----	n.d.	n.d.	n.d.	-----	-----	-----
Alachlor, Total (ug/l)(C)	0.07	5	-----	n.d.	n.d.	n.d.	760(5), 76(6)	0	0%
Atrazine, Total (ug/l)(C)	0.13	5	-----	n.d.	n.d.	0.21	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l)(C)	0.03	5	-----	n.d.	n.d.	n.d.	390(5), 100(6)	0	0%
Pesticide Scan (ug/l)(D)	0.05						-----	-----	-----
Atrazine		24	-----	0.10	n.d.	0.33	330(5), 12(6)	0	0%
Metolachlor		25	-----	n.d.	n.d.	0.30	390(5), 100(6)	0	0%
Acetochlor		15	-----	n.d.	n.d.	0.30	-----	-----	-----
Profluralin		1	-----	n.d.	n.d.	0.49	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l microcystins in recreation water for impairment assessment.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 36. Summary of water quality conditions monitored in Standing Bear Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site STBLKML1) from May to September during the 5-year period 2006 through 2011. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements.]

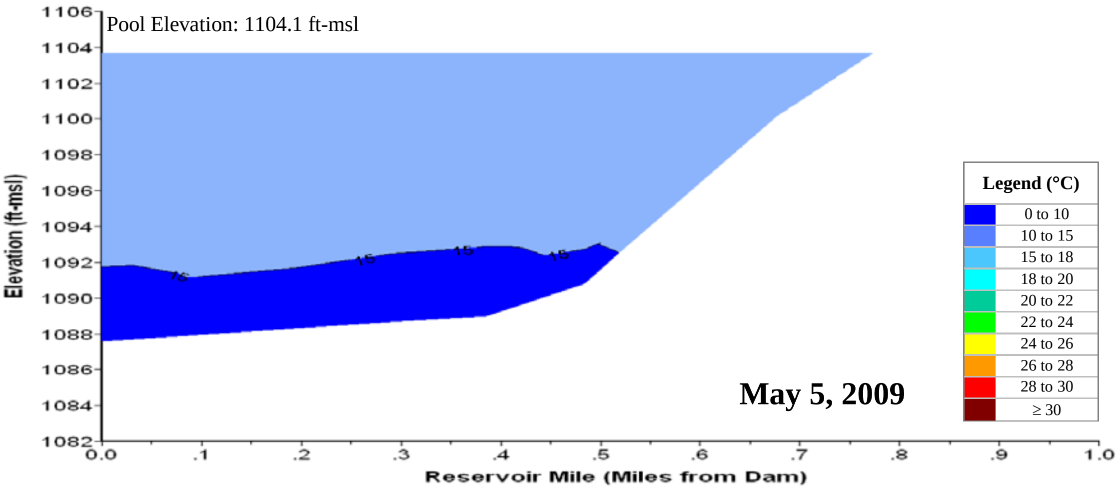
Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A,C)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	24	1104.2	1104.3	1102.8	1105.3	-----	-----	-----
Water Temperature (°C)	0.1	274	22.2	22.4	13.3	30.2	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	265	6.2	6.7	0.2	11.7	≥ 5(2)	82	31%
Dissolved Oxygen (% Sat.)	0.1	253	72.7	81.9	1.9	162.6	-----	-----	-----
Specific Conductance (umho/cm)	1	262	403	384	234	682	2,000(3)	-----	-----
pH (S.U.)	0.1	250	8.1	8.2	6.6	9.5	≥6.5 & ≤9.0(1)	0,5	2%
Turbidity (NTUs)	1	253	16	15	0	188	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	262	295	319	-130	433	-----	-----	-----
Secchi Depth (in.)	1	25	33	24	15	81	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	207	25	17	2	199	16(4)	114	55%

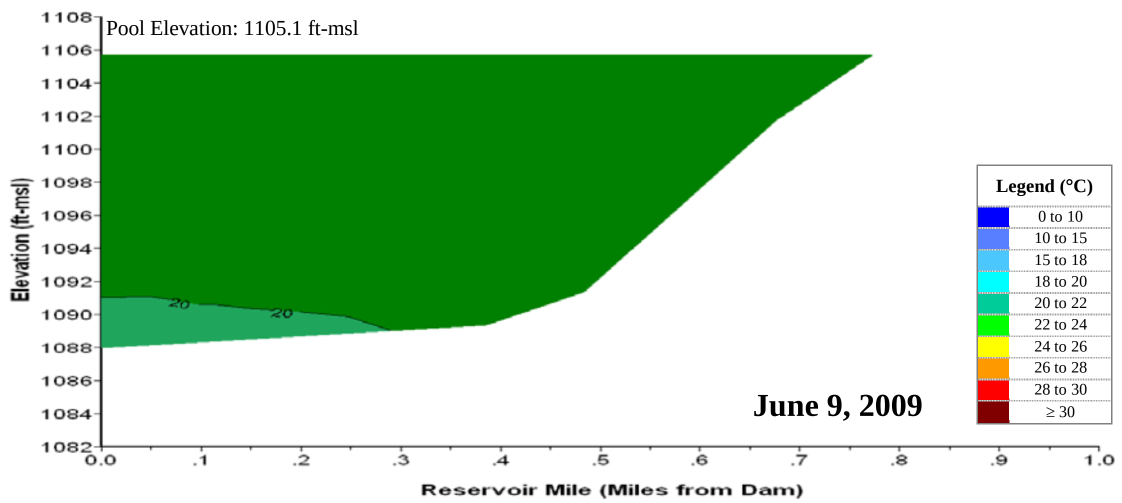
n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2008 Section 303(d) impairment assessment criteria





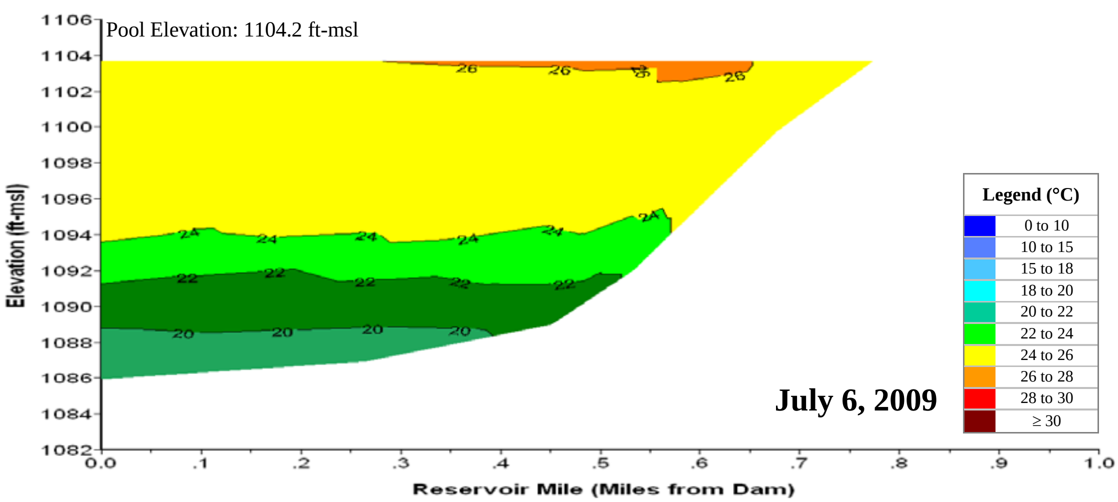
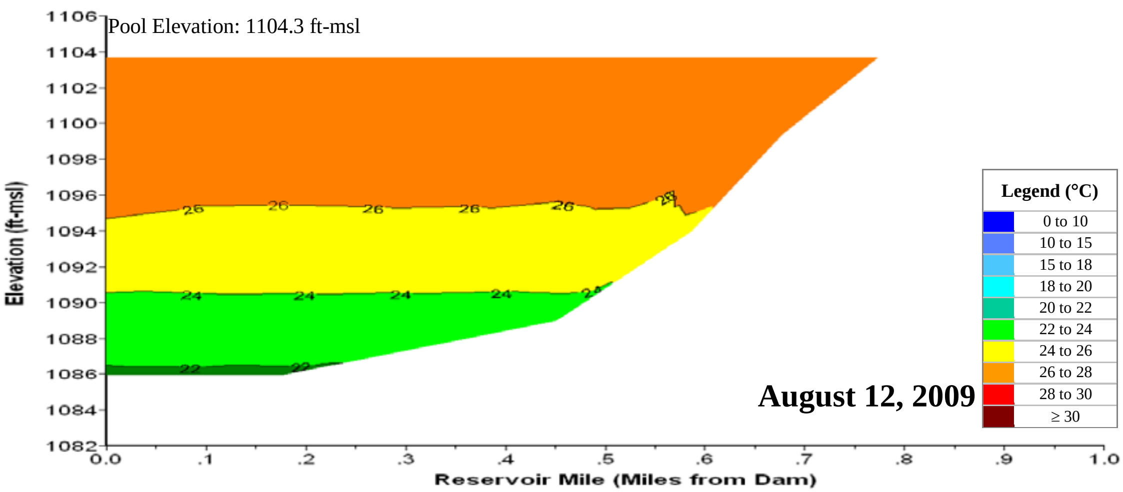


Plate 37. Longitudinal water temperature contour plots of Standing Bear Reservoir based on depth-profile water temperatures (°C) measured at sites STBLKND1 and STBLKML1 in 2009.



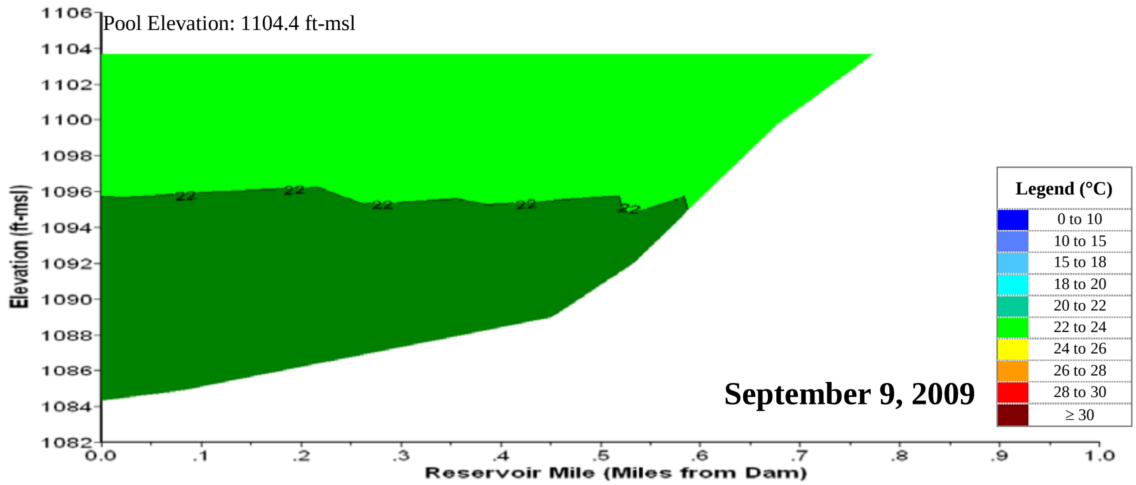


Plate 37. (Continued).

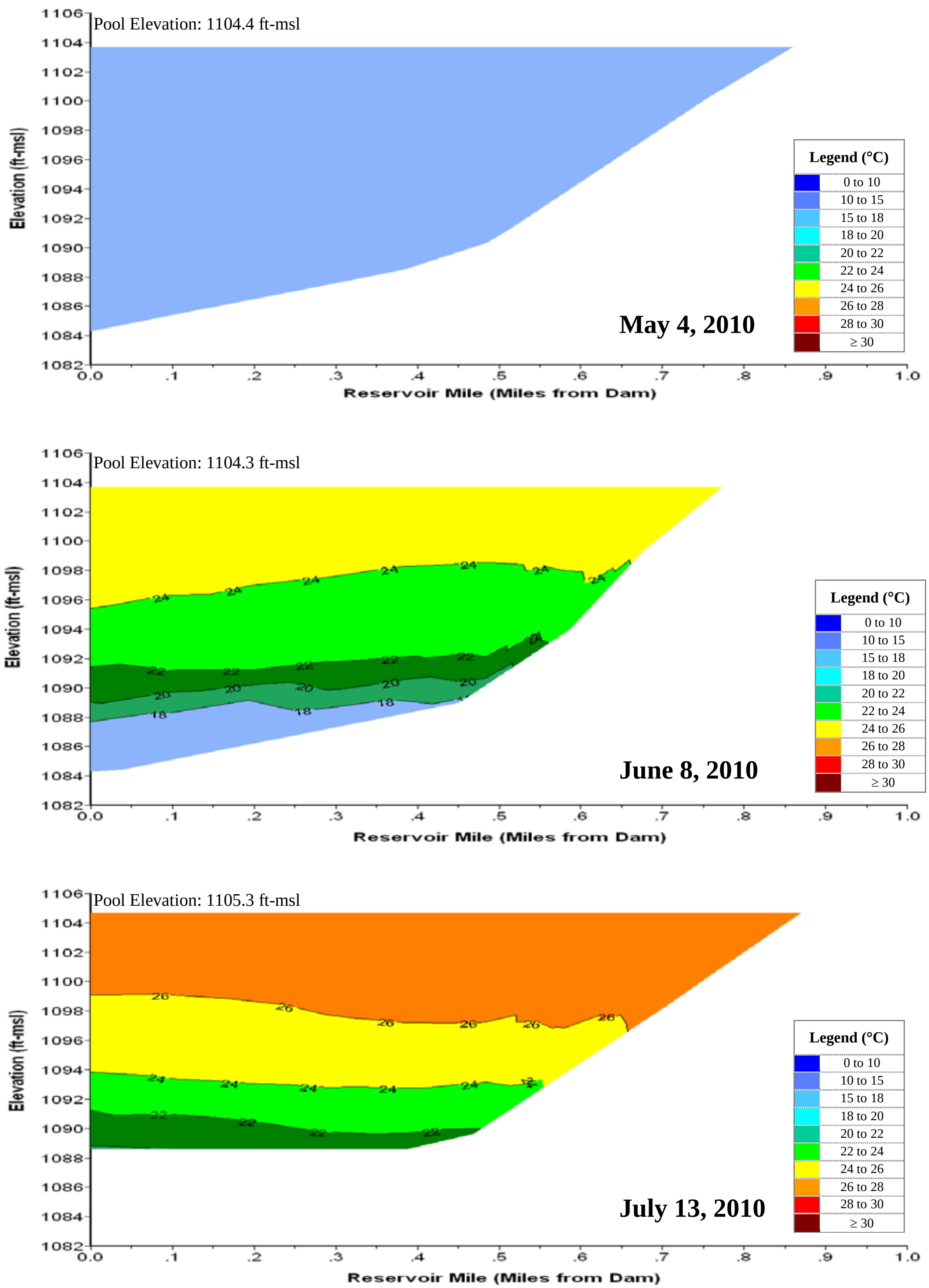
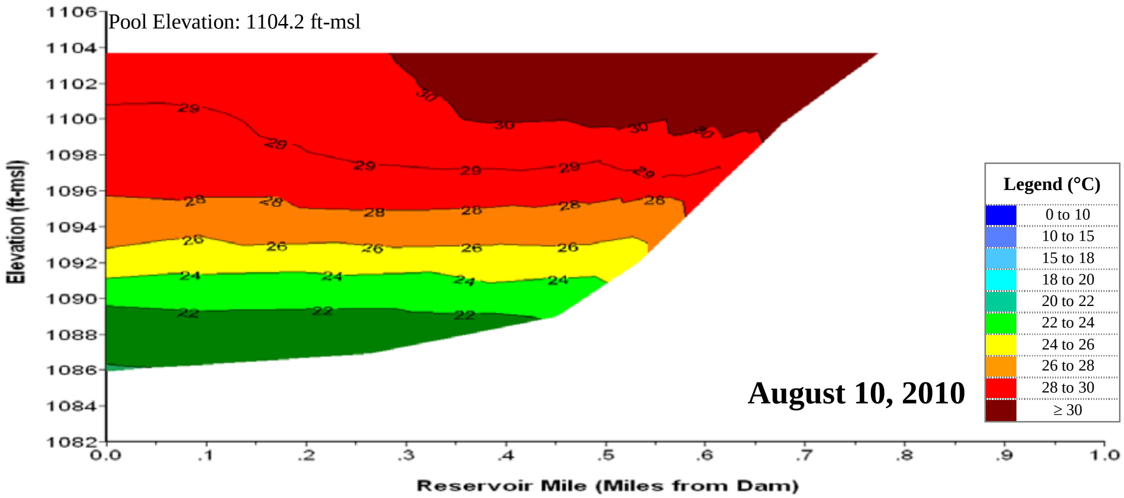


Plate 38. Longitudinal water temperature contour plots of Standing Bear Reservoir based on depth-profile water temperatures (°C) measured at sites STBLKND1, STBLKML1, and STBLKUPN1 in 2010.



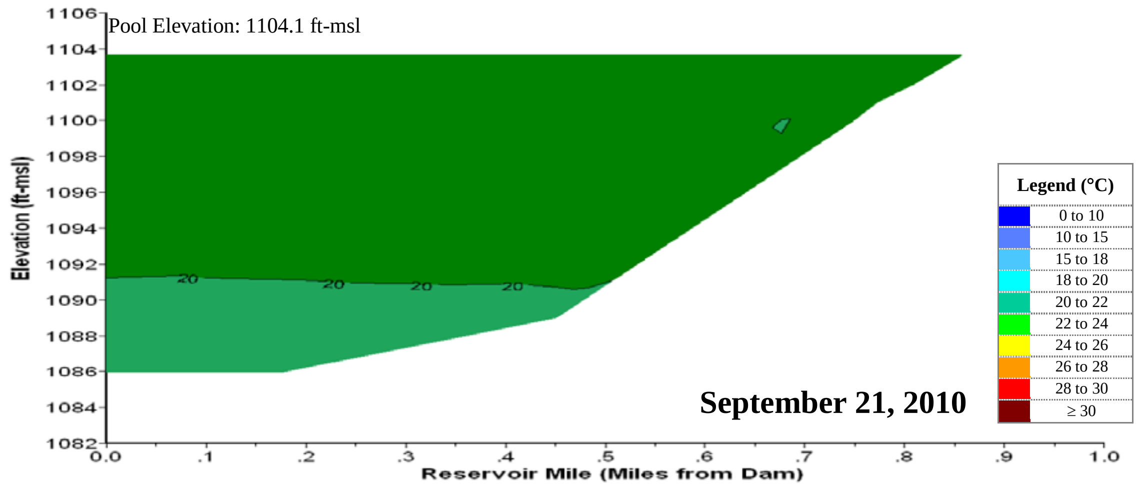


Plate 39. (Continued).

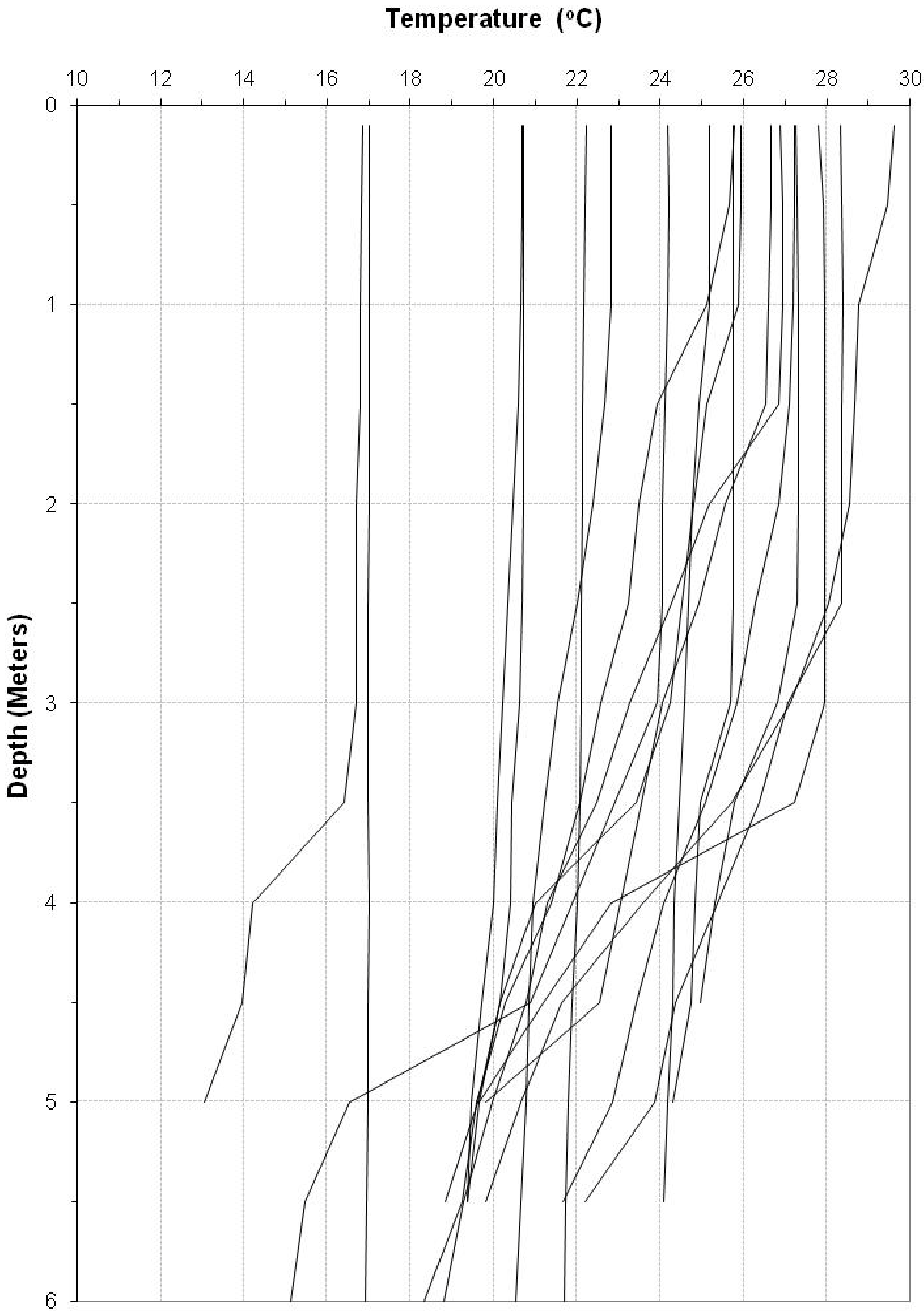


Plate 39. Temperature depth profiles for Standing Bear Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., STBLKND1) during the summer over the 5-year period of 2006 through 2010.

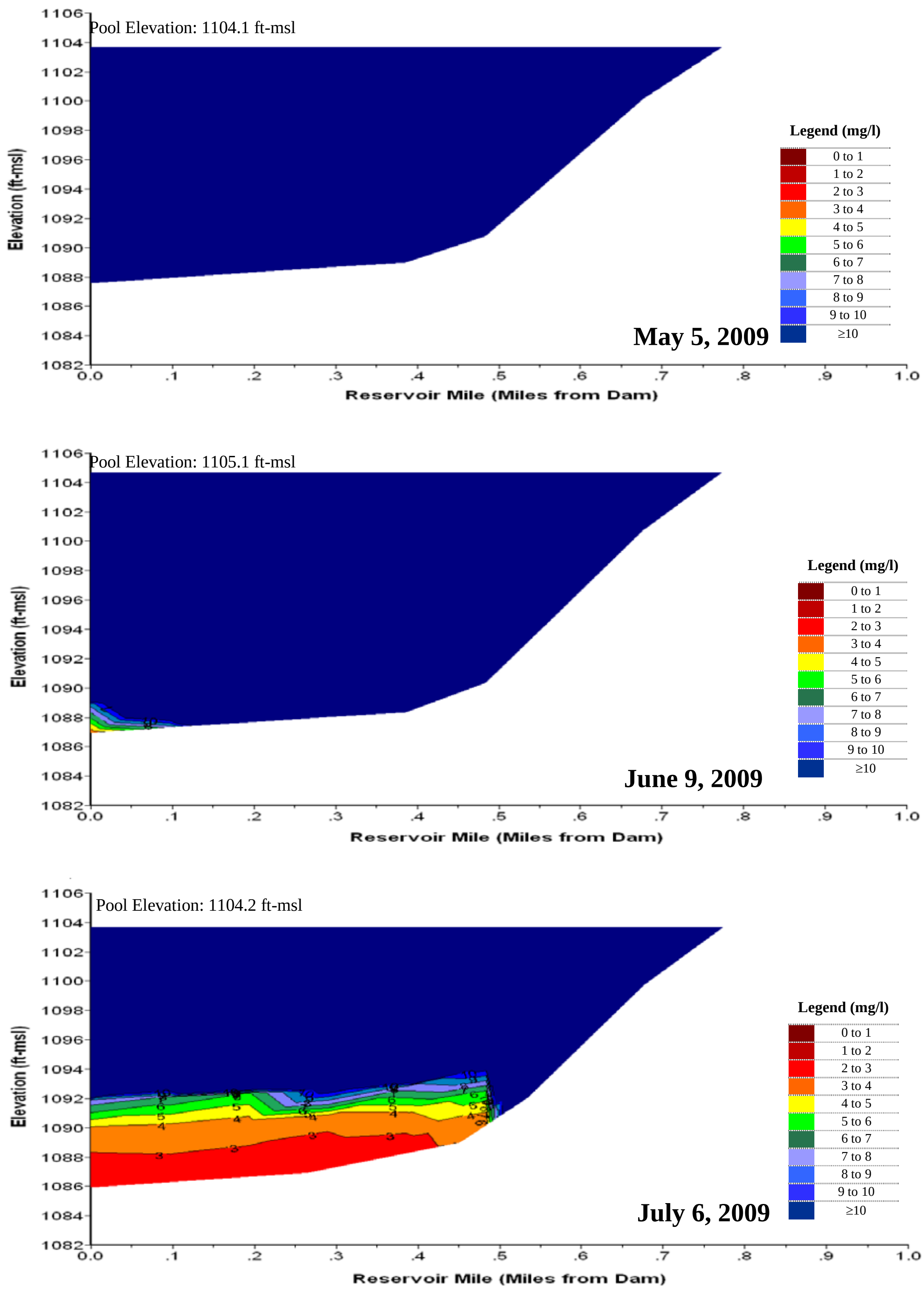
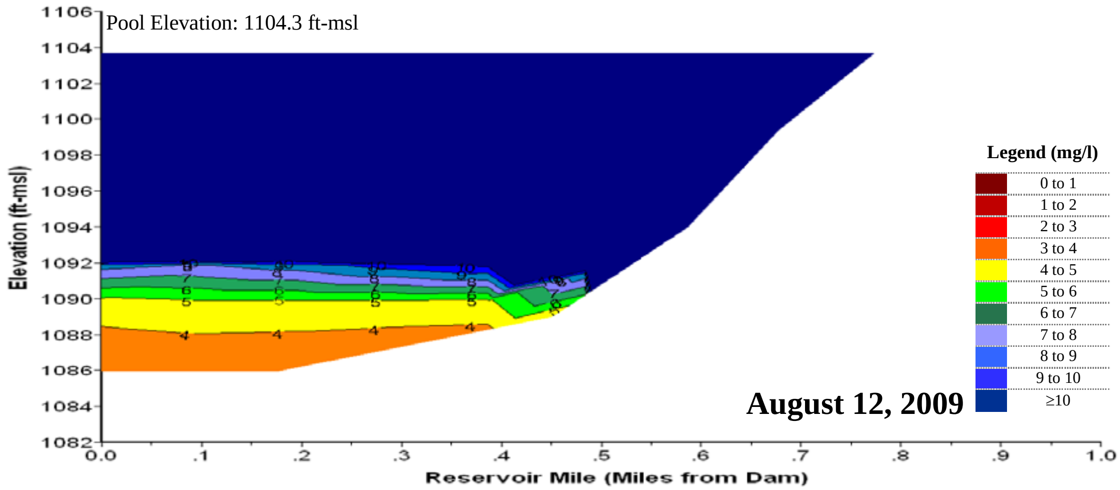


Plate 40. Longitudinal dissolved oxygen contour plots of Standing Bear Reservoir based on depth-profile dissolved oxygen concentrations (mg/l) measured at sites STBLKND1 and STBLKML1 in 2009.



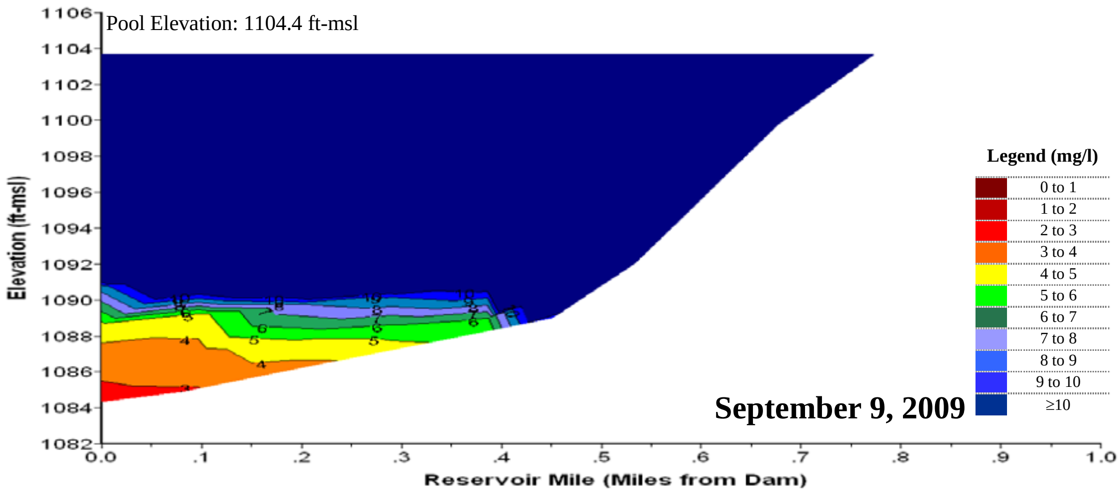


Plate 40. (Continued).

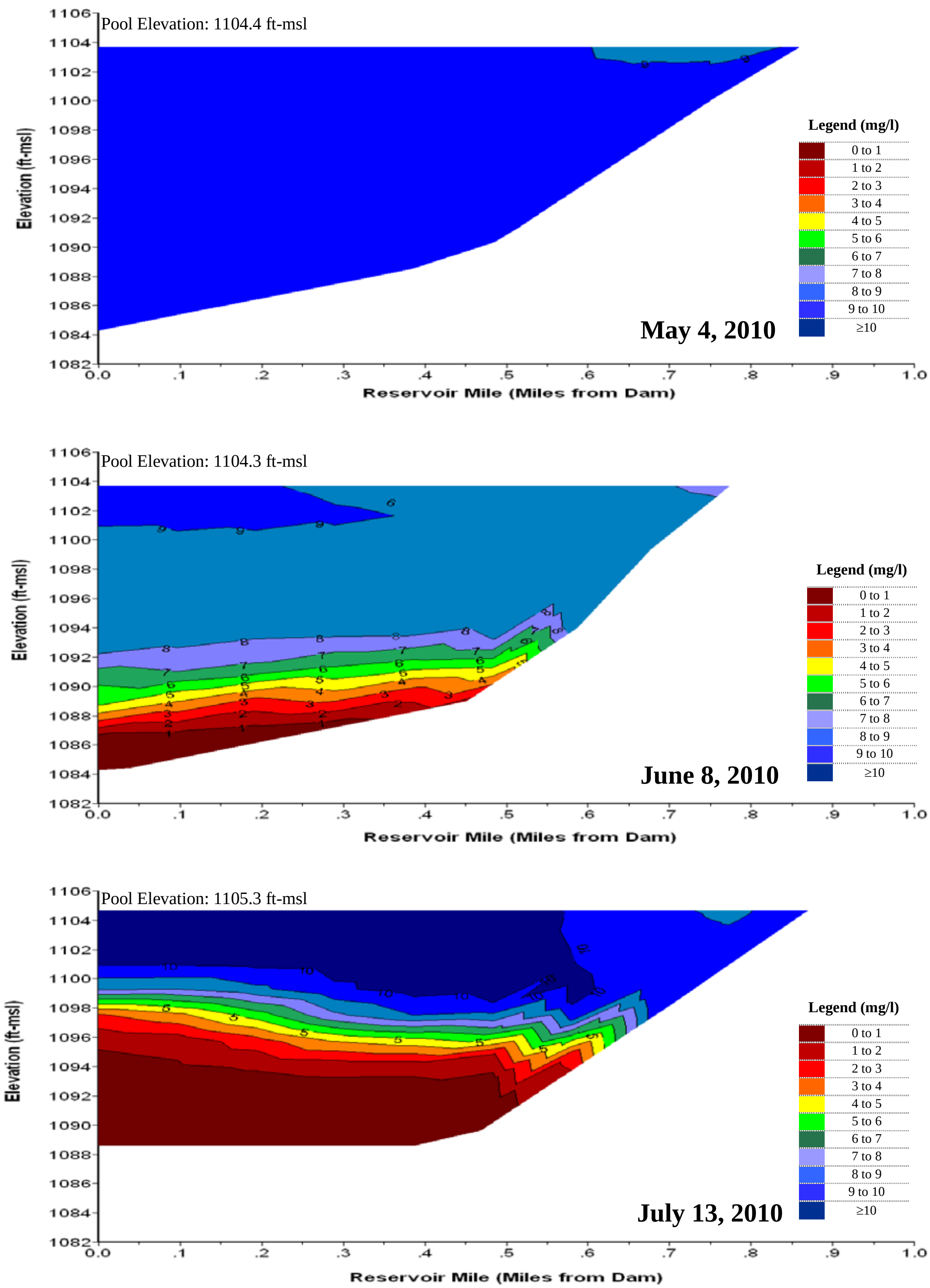
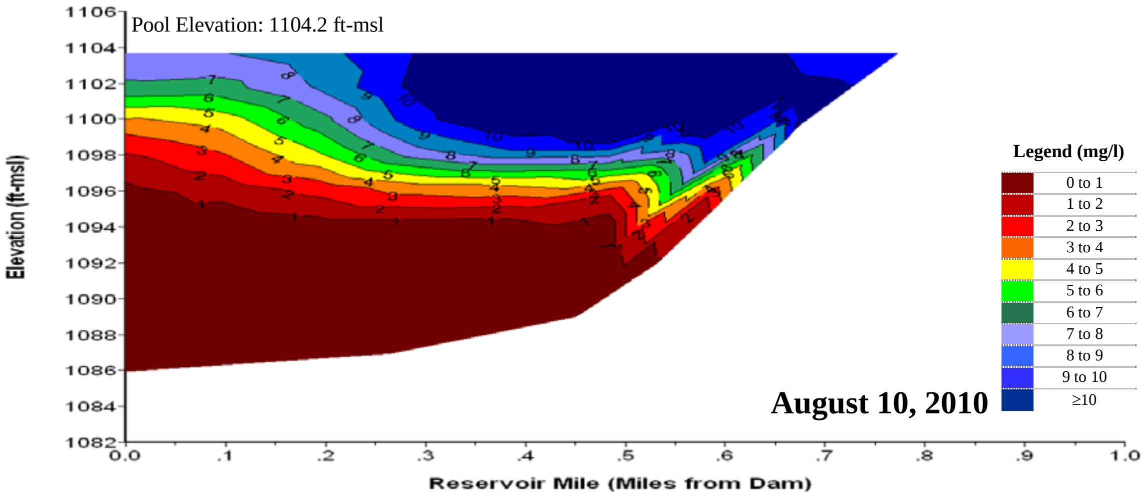


Plate 41. Longitudinal dissolved oxygen contour plots of Standing Bear Reservoir based on depth-profile dissolved oxygen concentrations (mg/l) measured at sites STBLKND1, STBLKML1, and STBLKUPN1 in 2010.



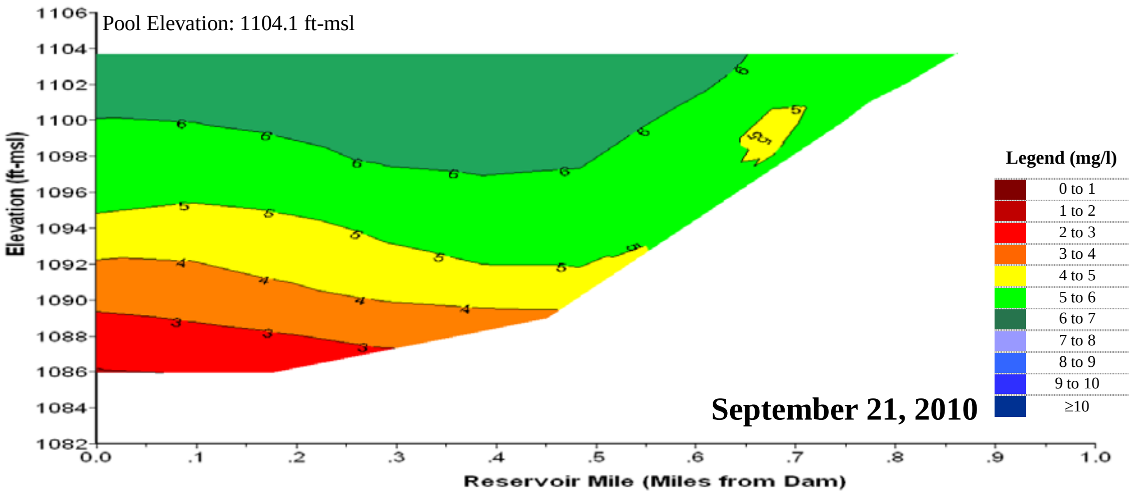


Plate 41. (Continued).

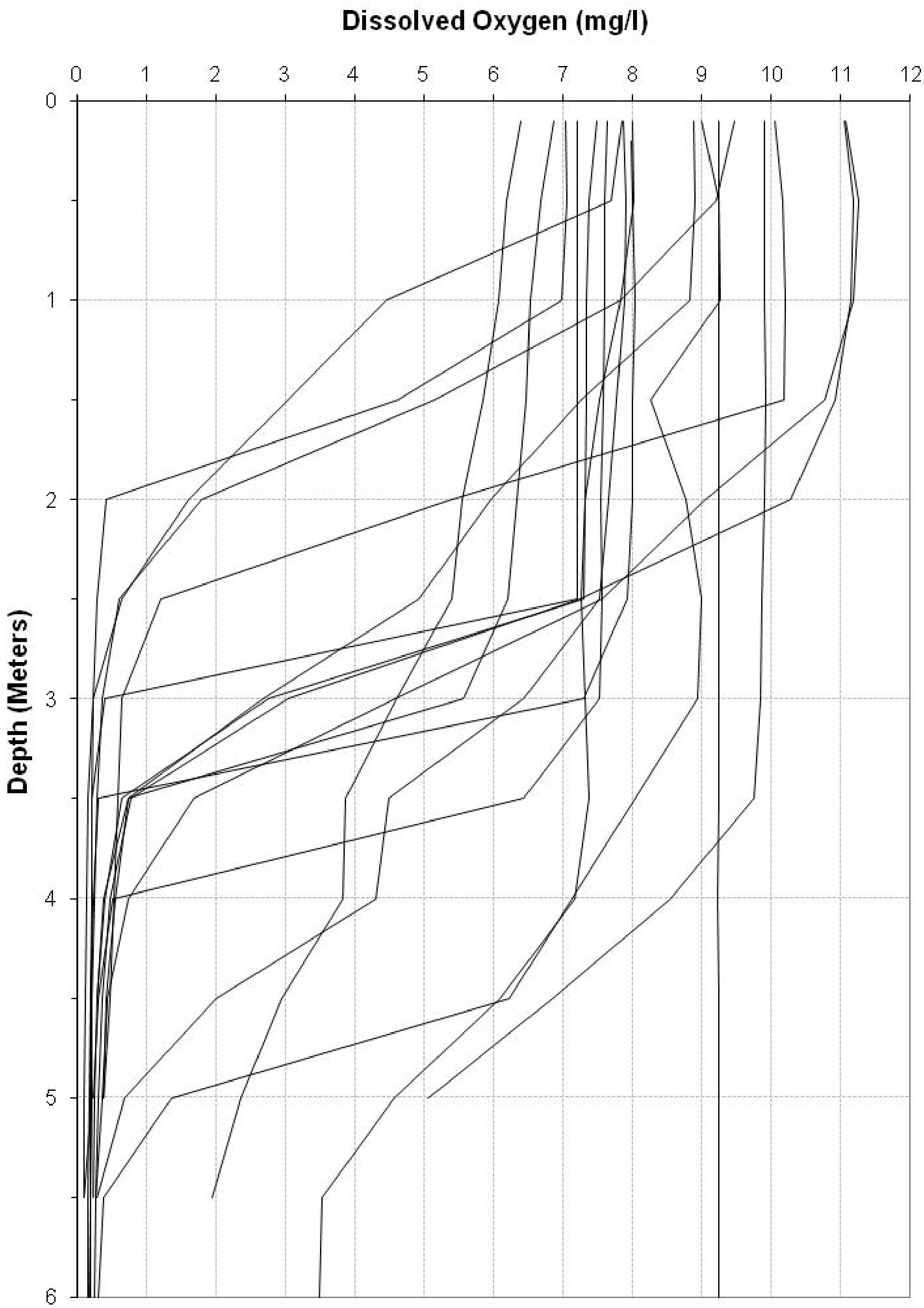


Plate 42. Dissolved oxygen depth profiles for Standing Bear Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., STBLKND1) during the summer over the 5-year period of 2006 through 2010.

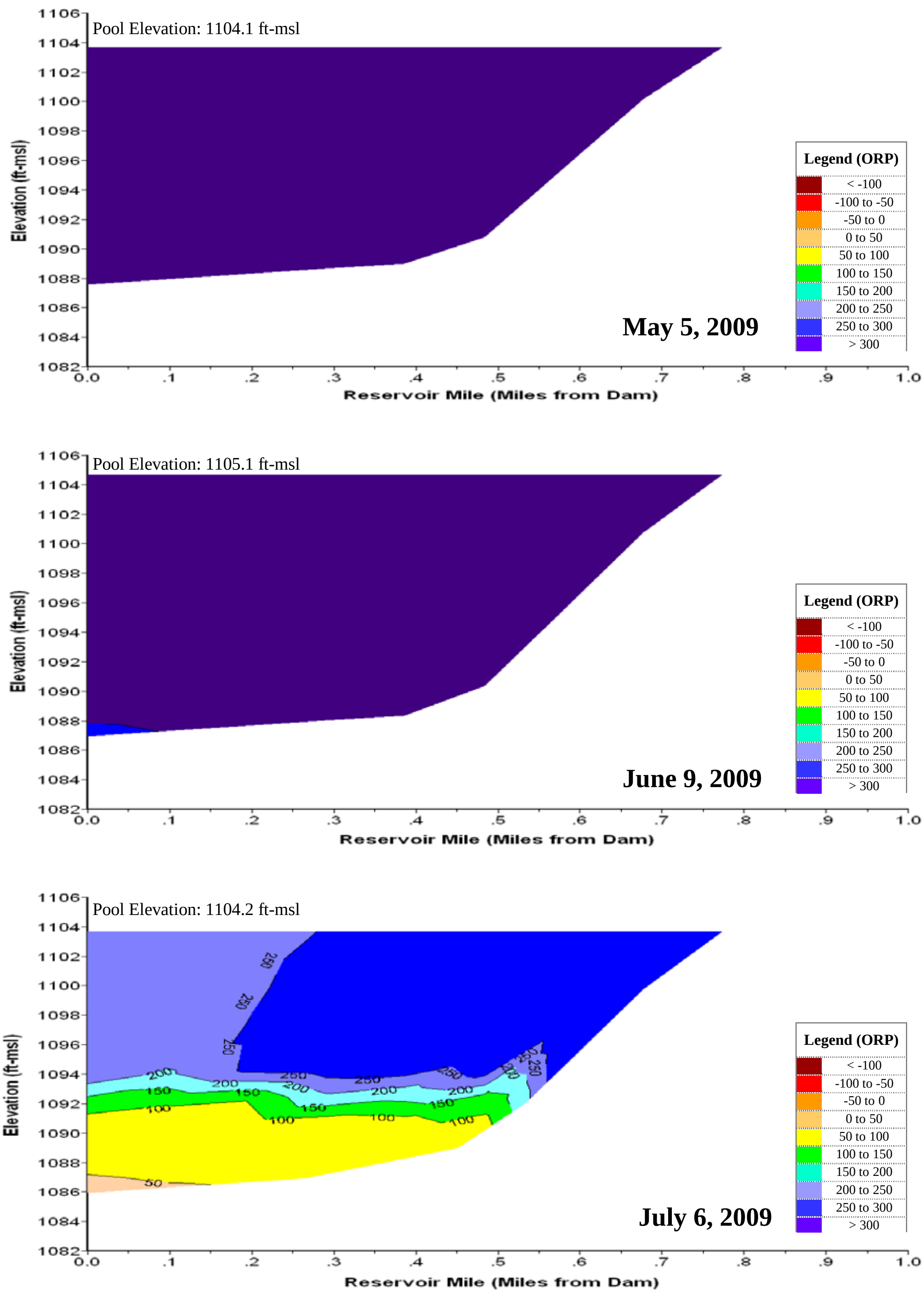
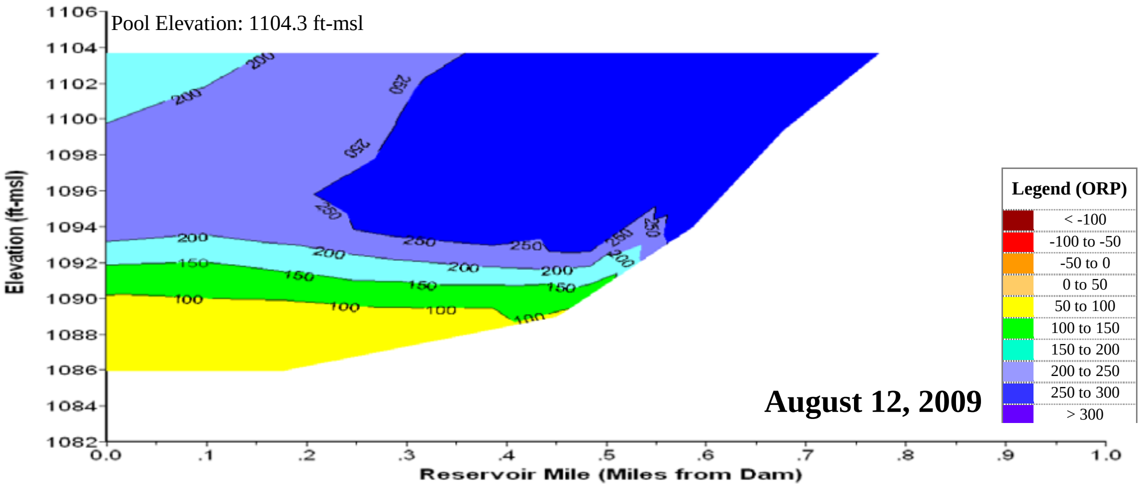


Plate 43. Longitudinal oxidation-reduction potential contour plots of Standing Bear Reservoir based on depth-profile ORP levels (mV) measured at sites STBLKND1 and STBLKML1 in 2009.



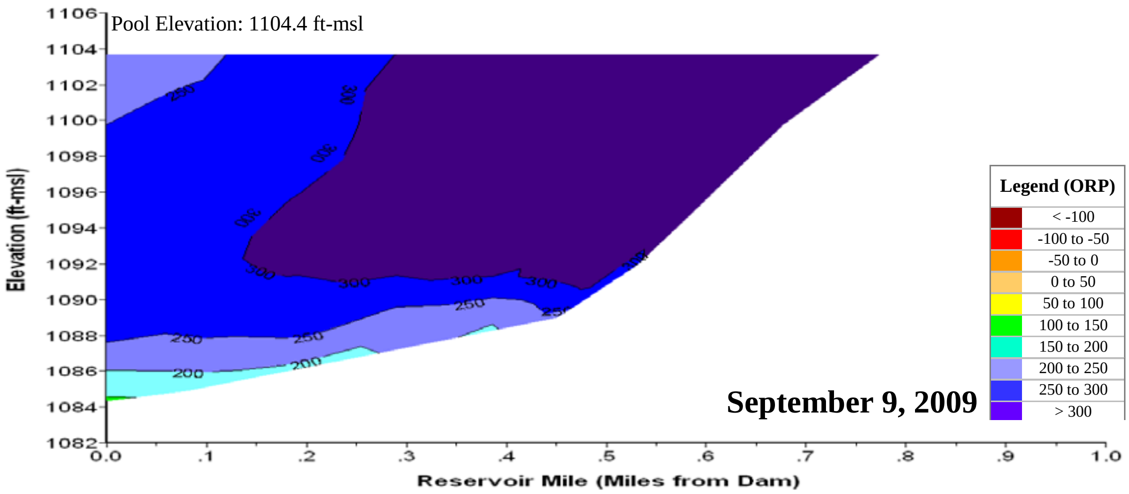


Plate 43. (Continued).

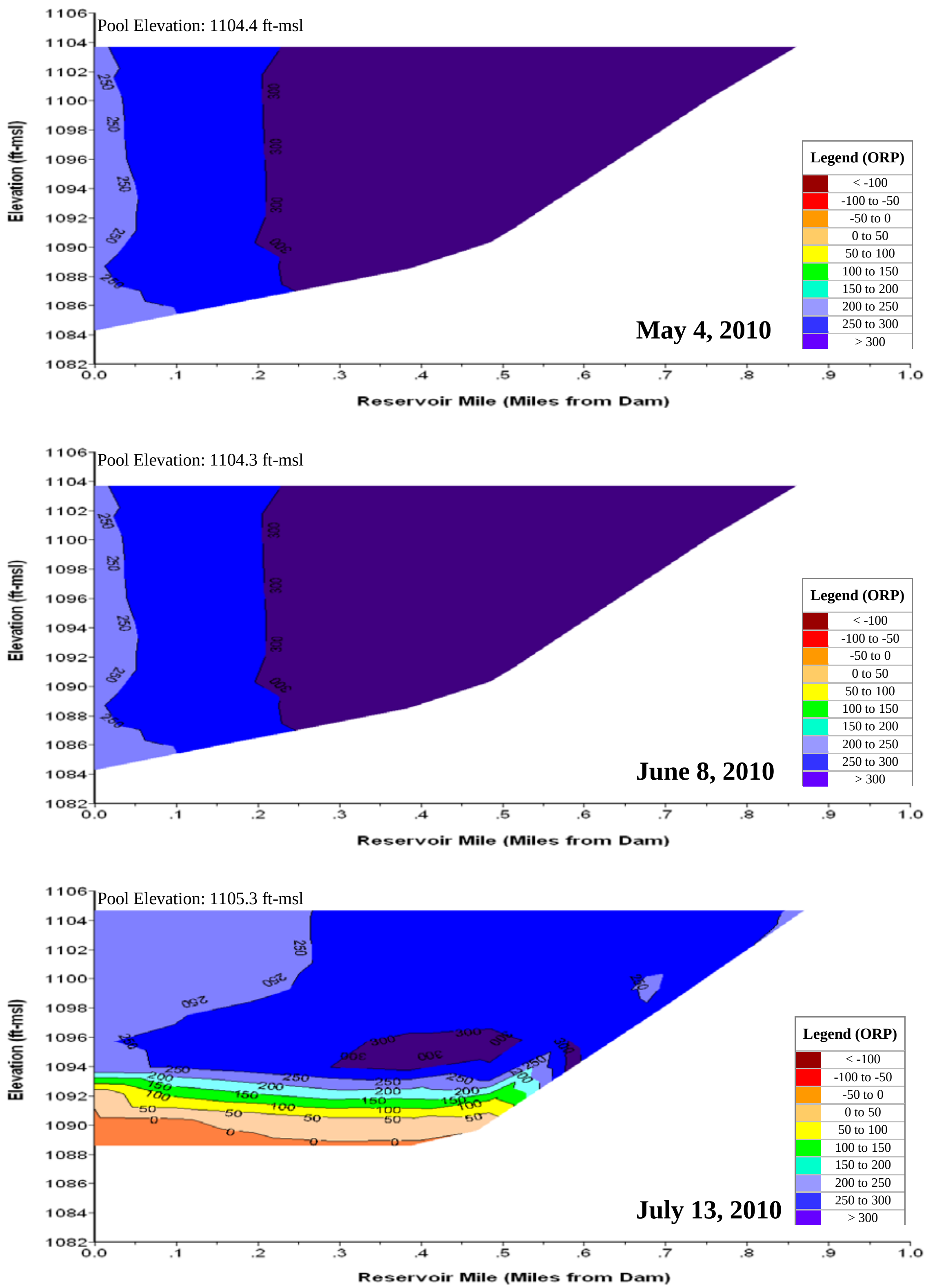
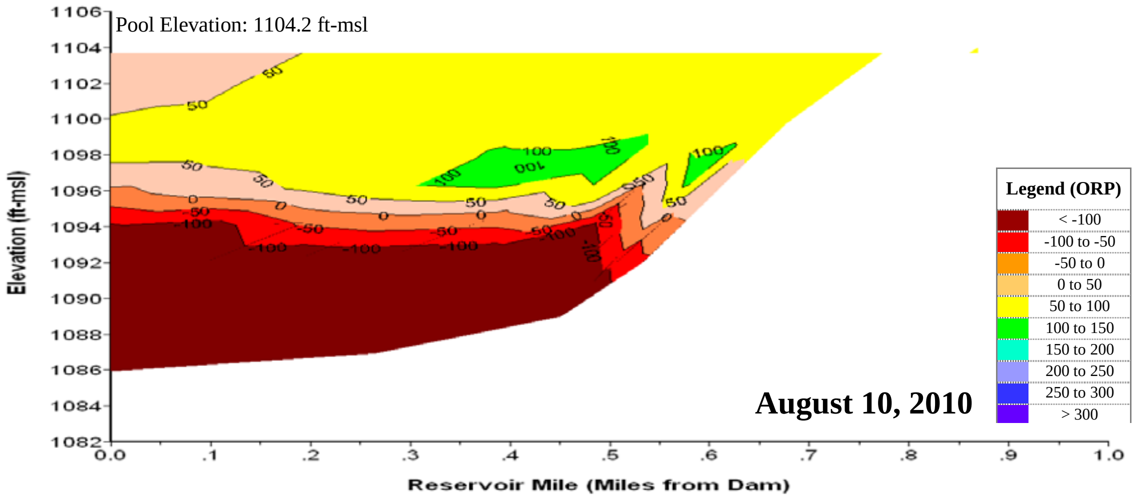


Plate 44. Longitudinal oxidation-reduction potential contour plots of Standing Bear Reservoir based on depth-profile ORP levels (mV) measured at sites STBLKND1, STBLKML1, and STBLKUPN1 in 2010.



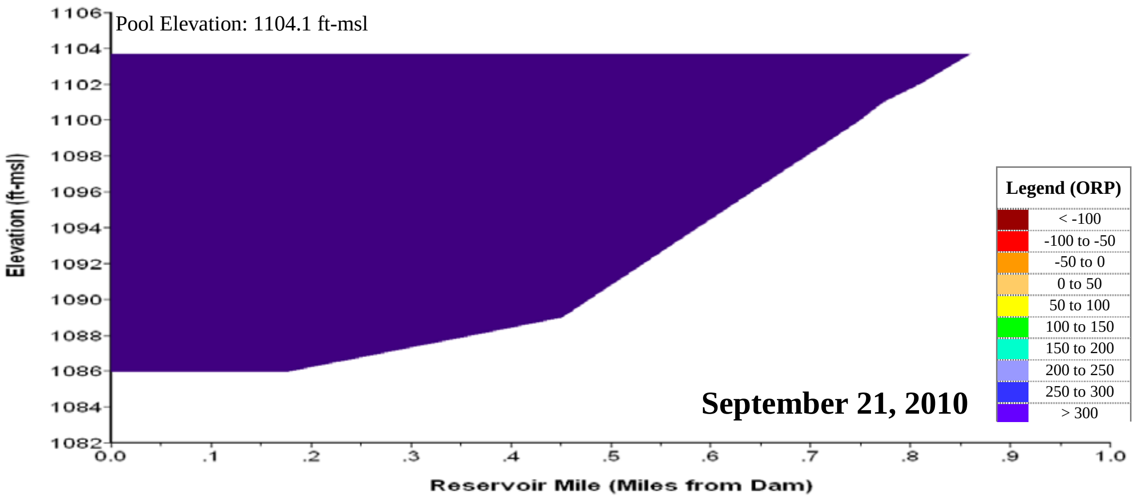


Plate 44. (Continued).

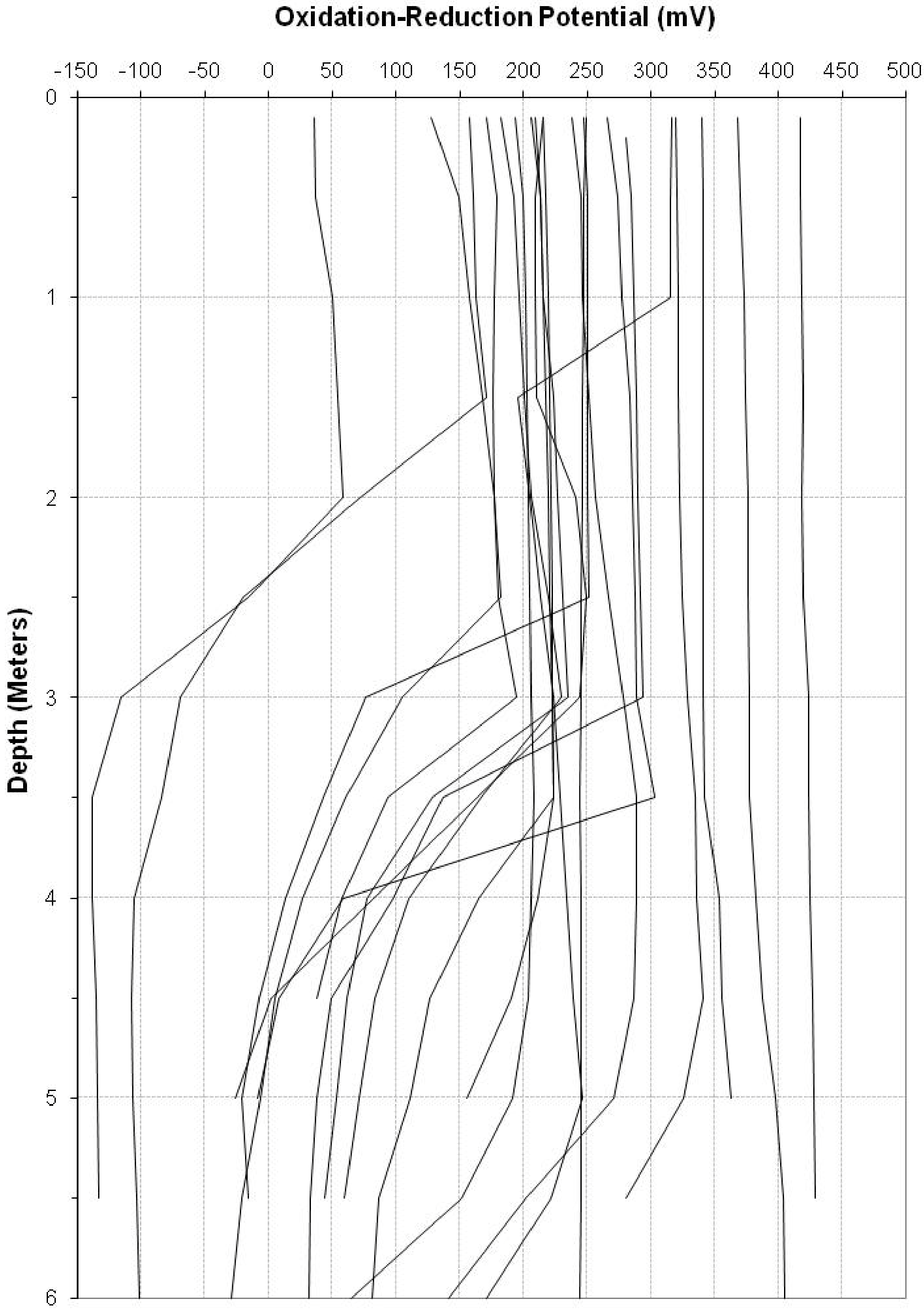


Plate 45. Oxidation-reduction potential depth profiles for Standing Bear Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., STBLKND1) during the summer over the 5-year period of 2006 through 2010.

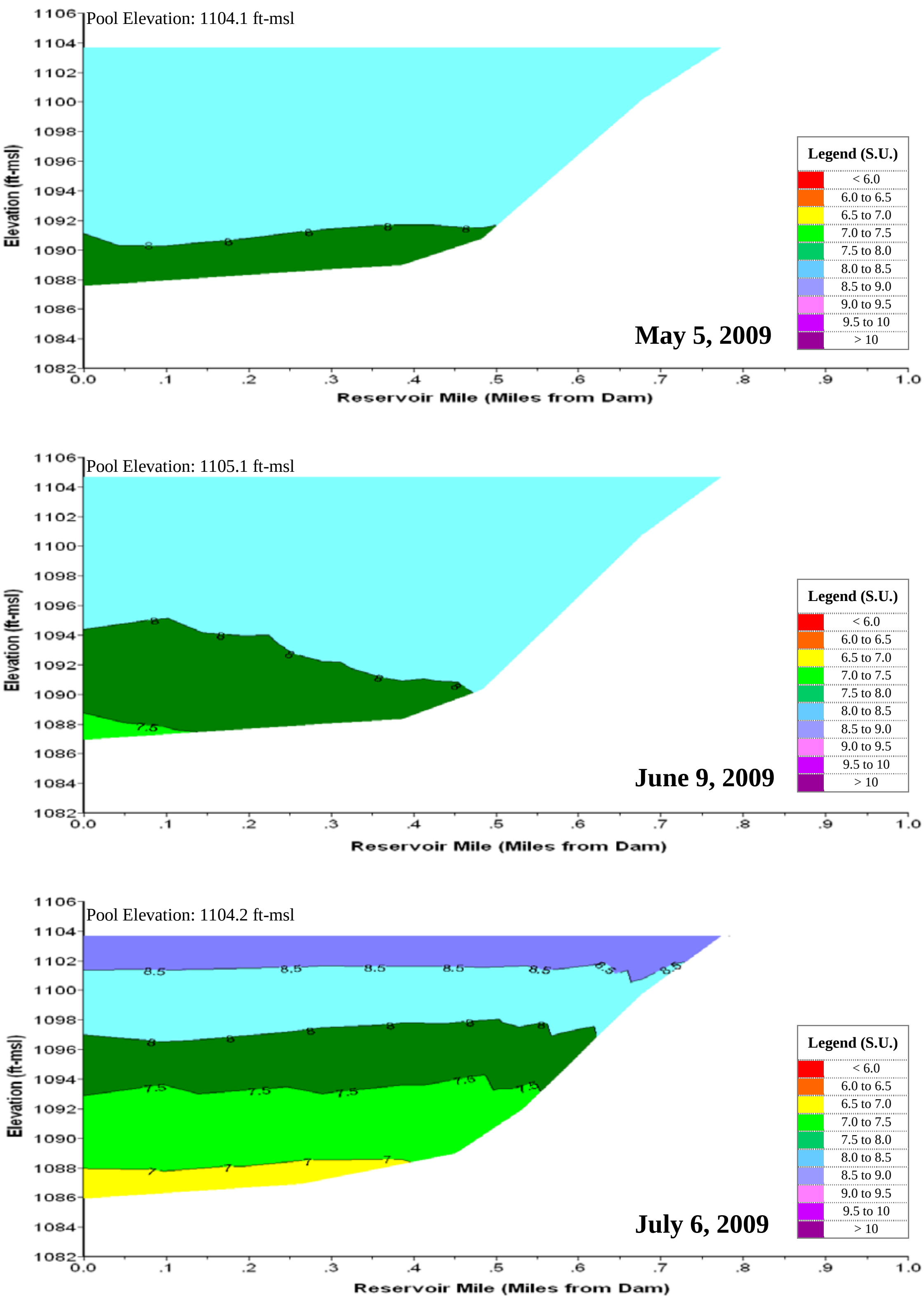
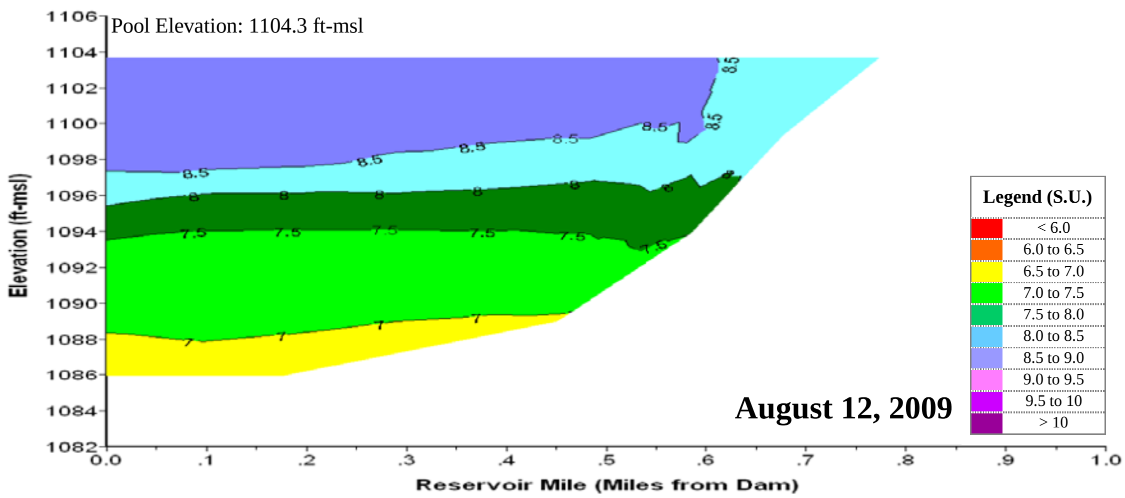


Plate 46. Longitudinal pH contour plots of Standing Bear Reservoir based on depth-profile pH levels (S.U.) measured at sites STBLKND1 and STBLKML1 in 2009.



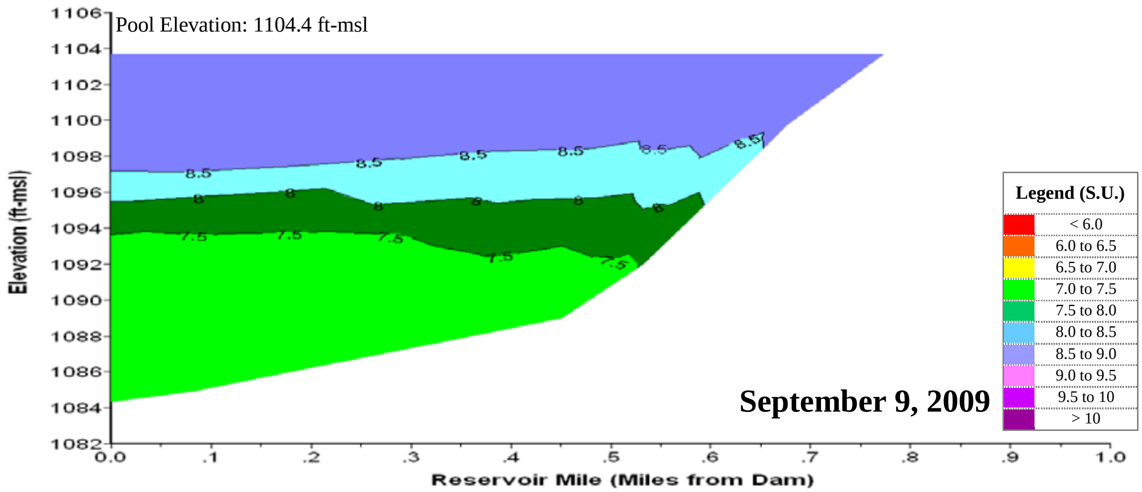


Plate 46. (Continued).

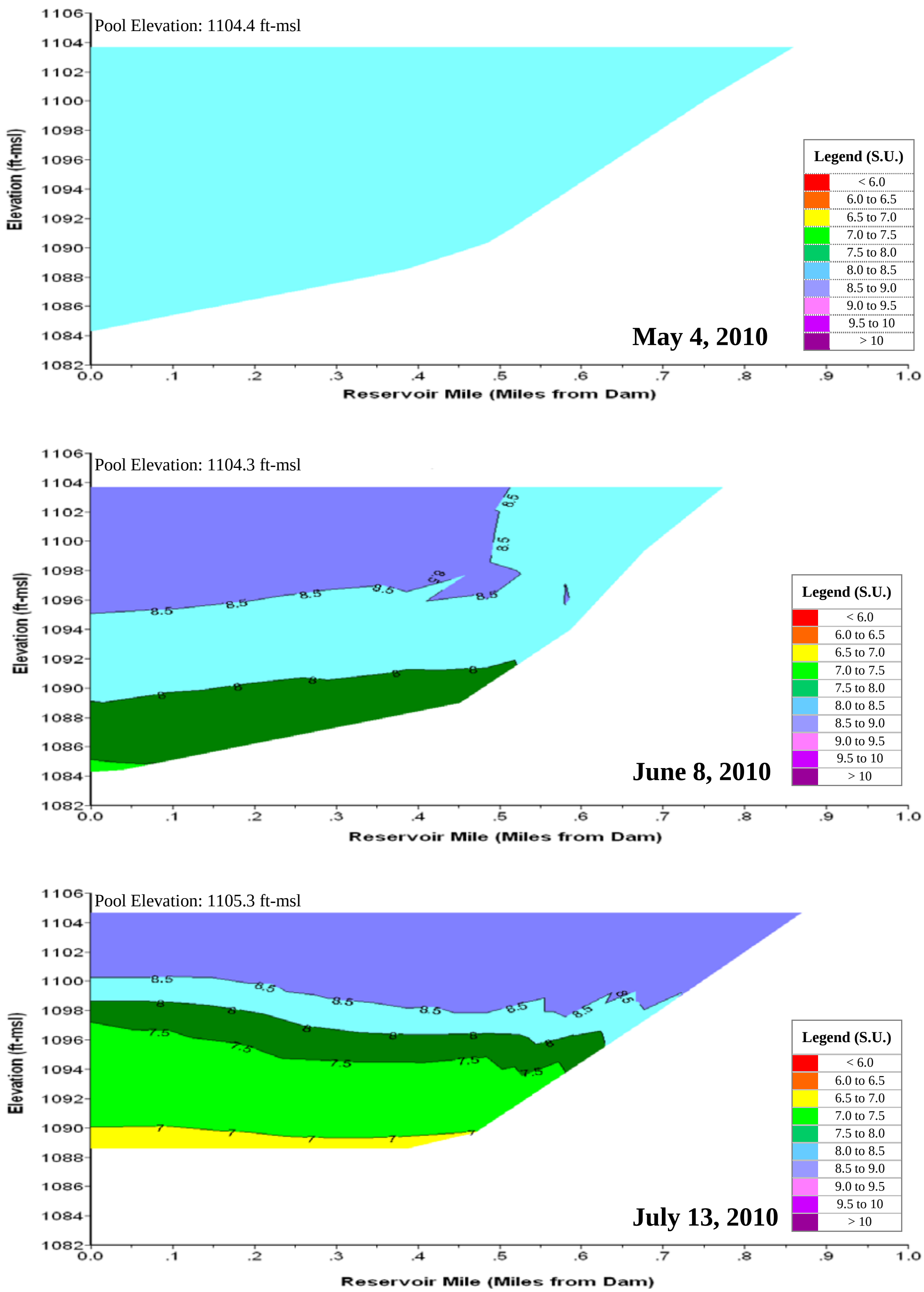
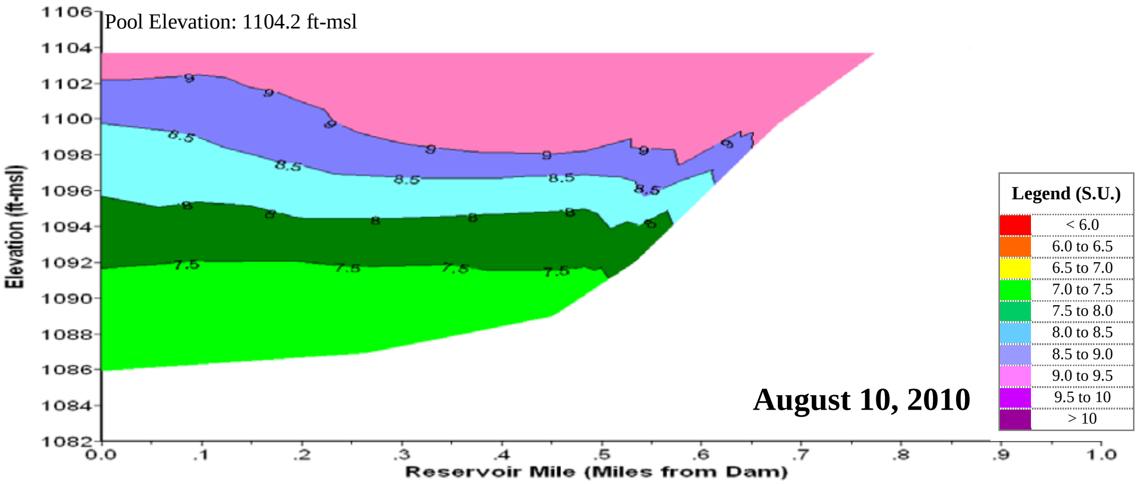


Plate 47. Longitudinal pH contour plots of Standing Bear Reservoir based on depth-profile pH levels (S.U.) measured at sites STBLKND1, STBLKML1, and STBLKUPN1 in 2010.



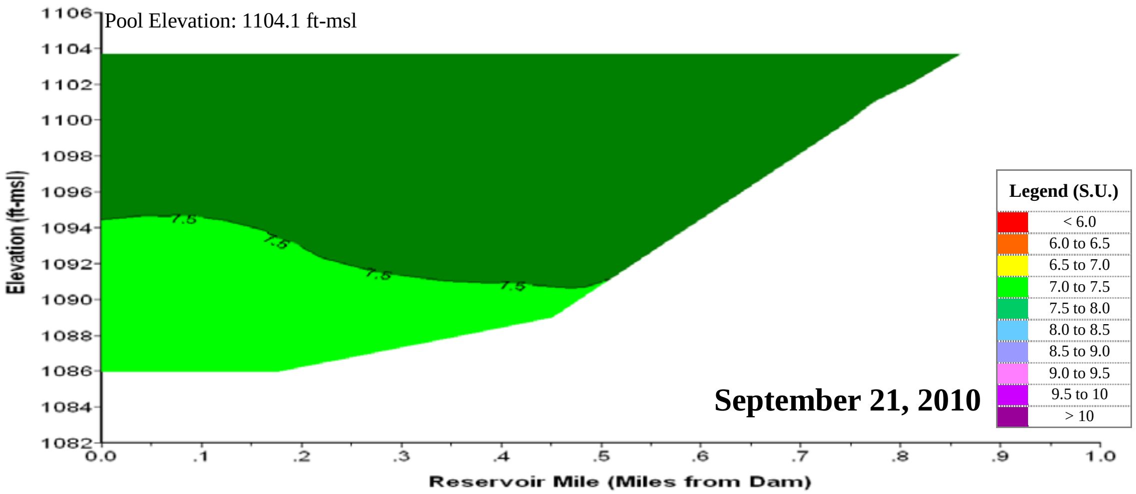


Plate 47. (Continued).

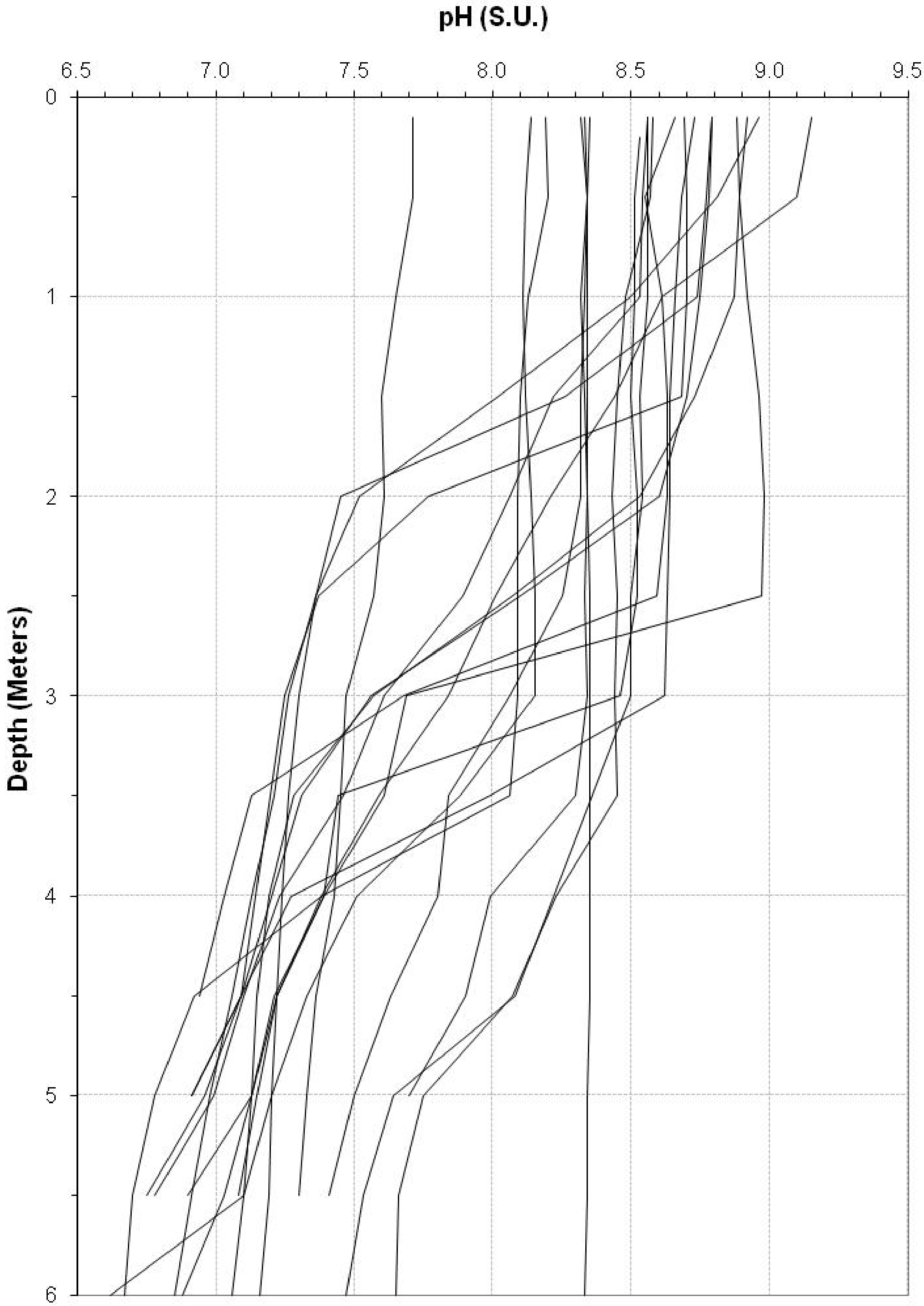


Plate 48. pH depth profiles for Standing Bear Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., STBLKND1) during the summer over the 5-year period of 2006 through 2010.

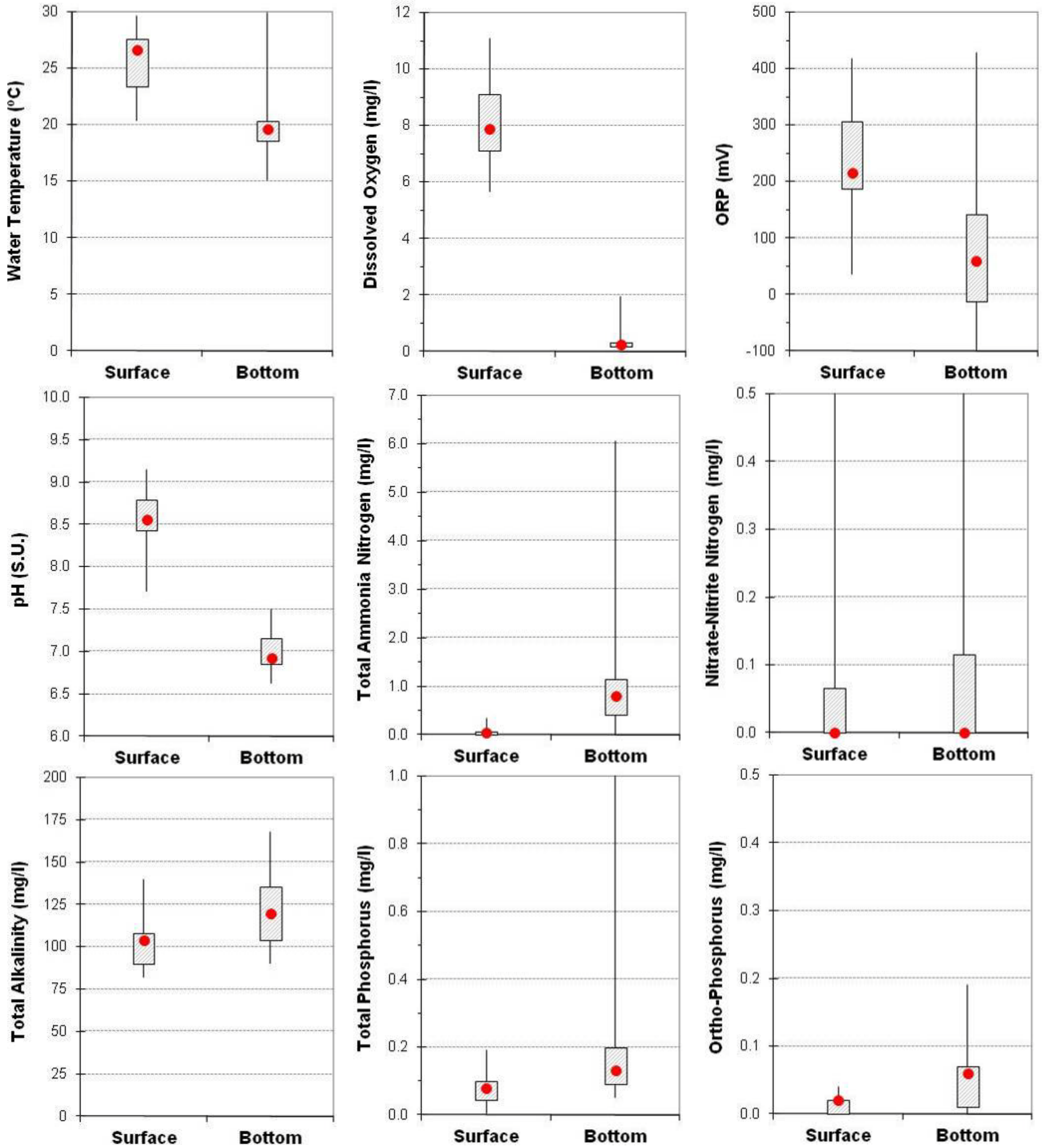


Plate 49. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, alkalinity, total ammonia nitrogen, nitrate-nitrite nitrogen, total phosphorus, and ortho-phosphorus measured in Standing Bear Reservoir during the 5-year period 2006 through 2010. (Box plots display minimum, 25^{th} percentile, 75^{th} percentile, and maximum. Median value is indicated by the red dot.)

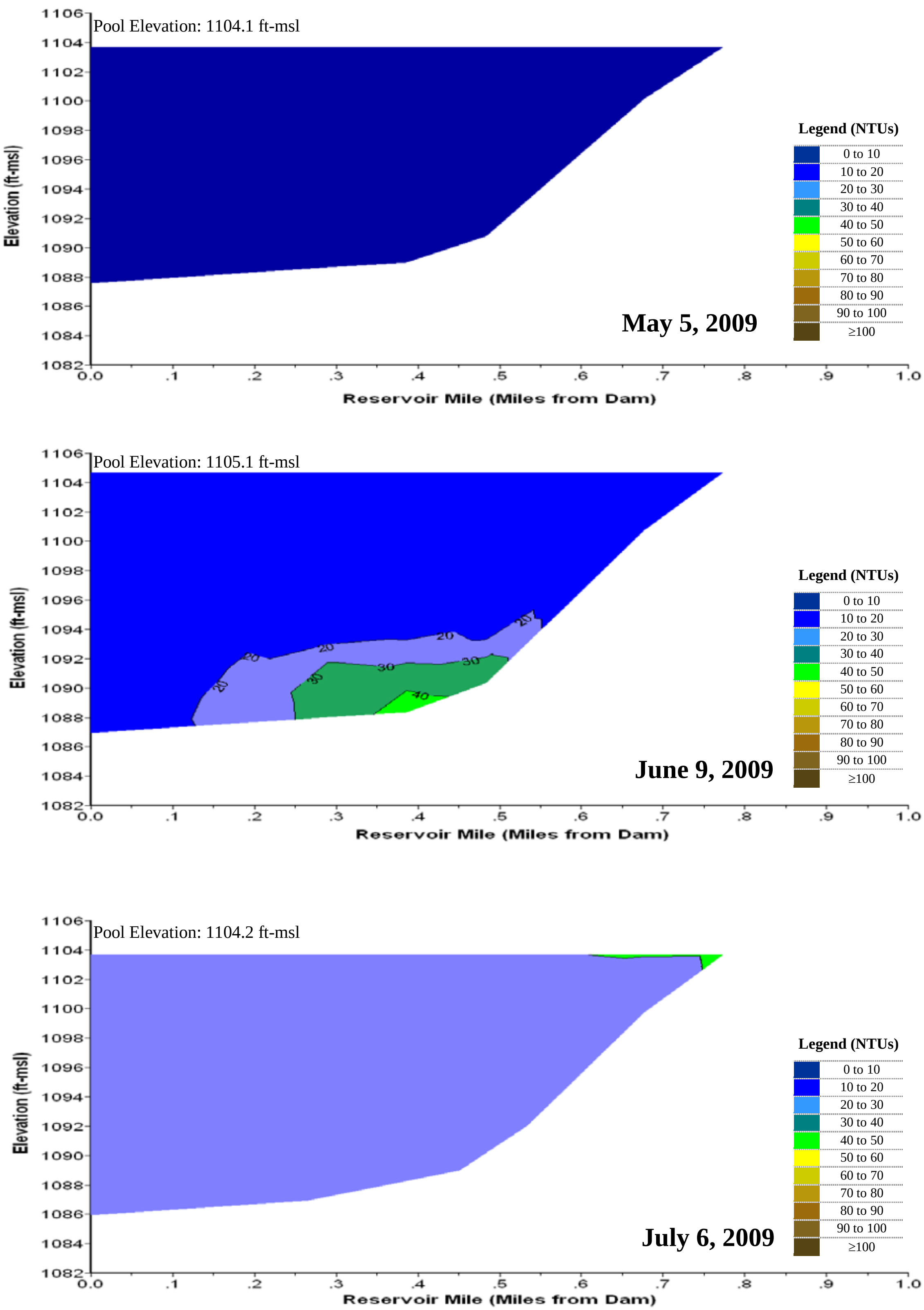
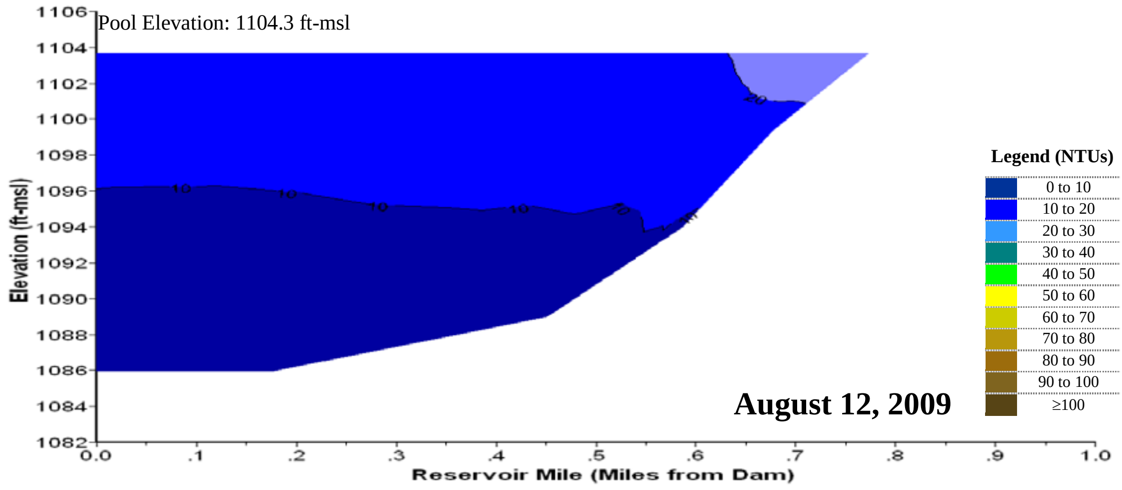


Plate 50. Longitudinal turbidity contour plots of Standing Bear Reservoir based on depth-profile turbidity levels (NTU) measured at sites STBLKND1 and STBLKML1 in 2009.



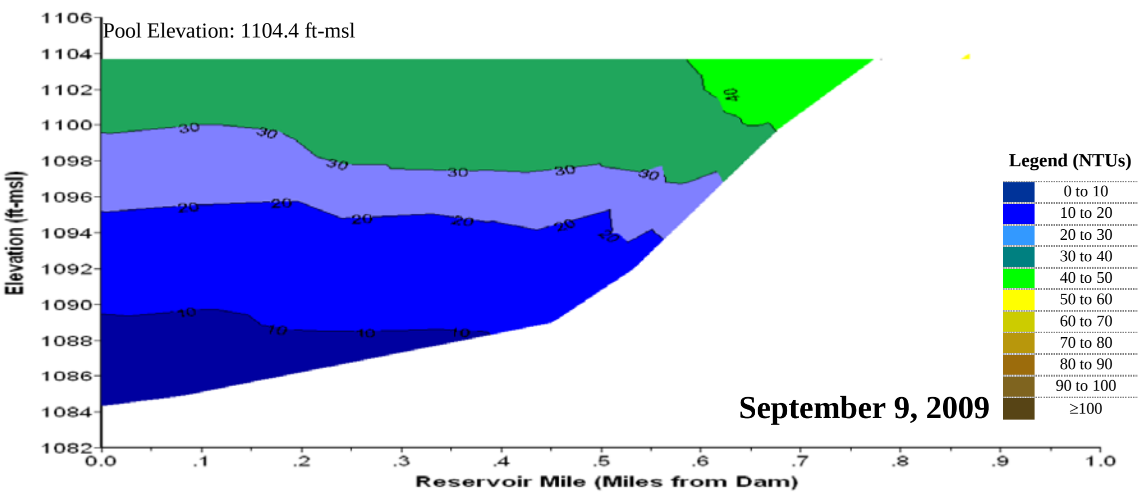


Plate 50. (Continued).

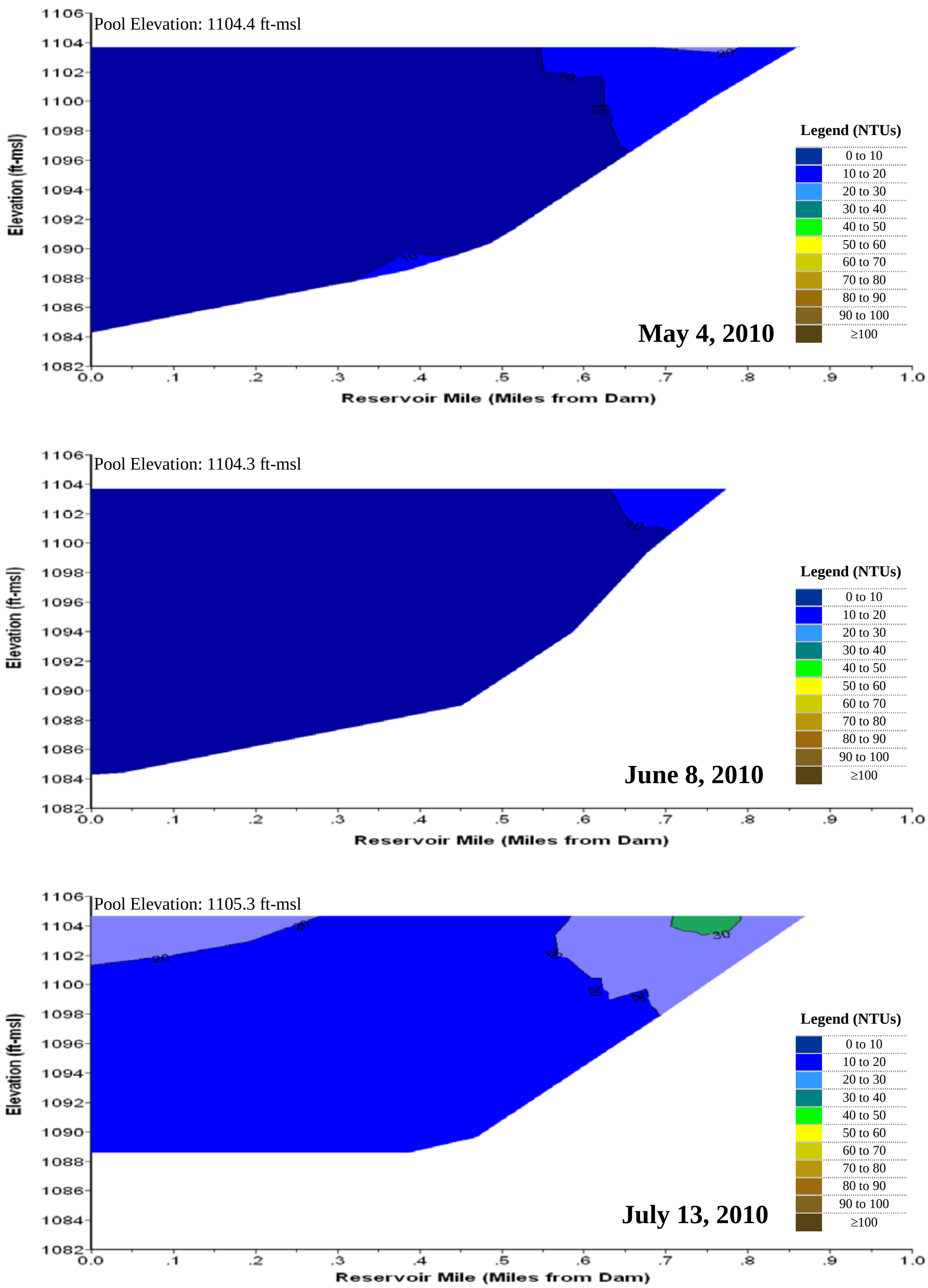
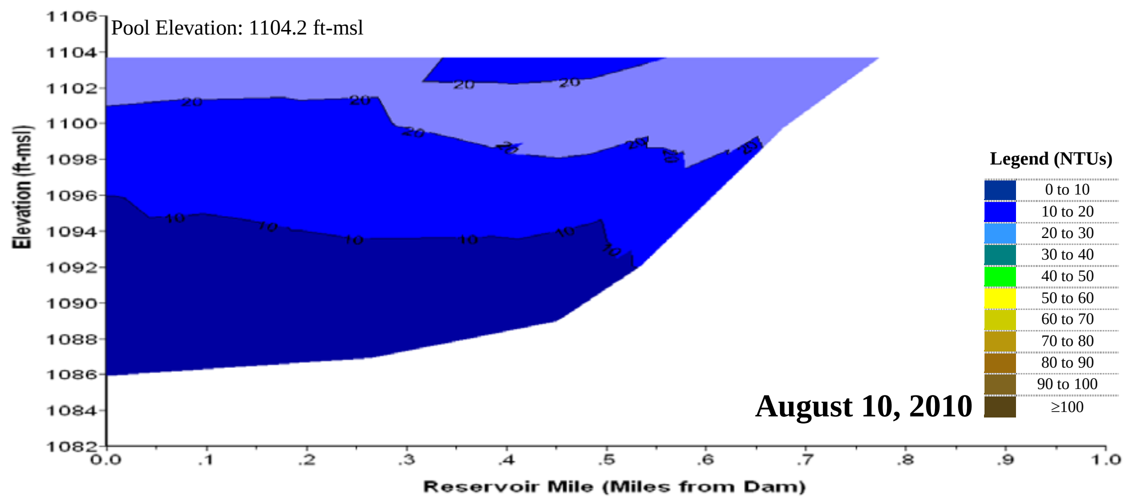


Plate 51. Longitudinal turbidity contour plots of Standing Bear Reservoir based on depth-profile turbidity levels (NTU) measured at sites STBLKND1, STBLKML1, and STBLKUPN1 in 2010.



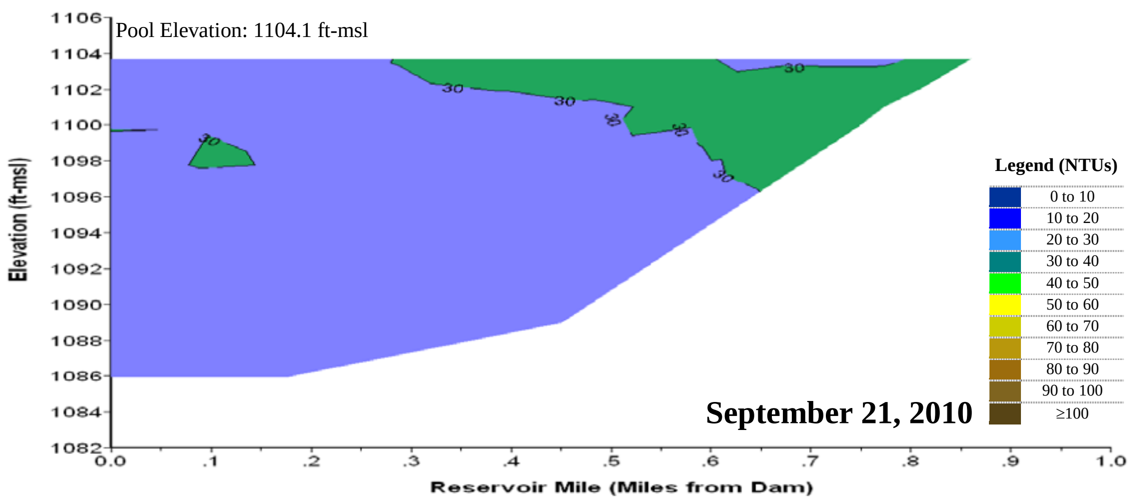


Plate 51. (Continued).

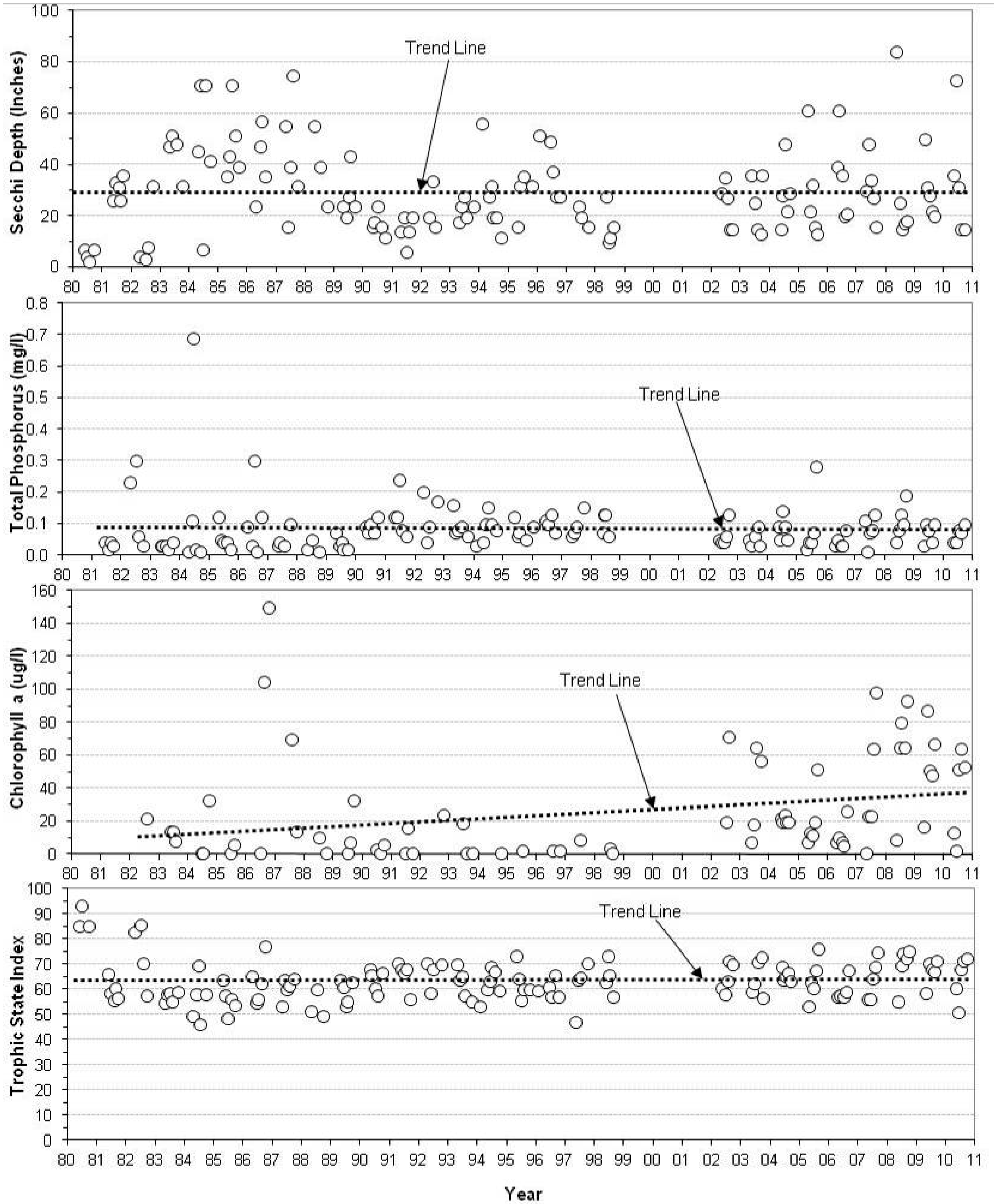


Plate 52. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Standing Bear Reservoir at the near-dam, ambient site (i.e., site STBLKND1) over the 30-year period of 1980 through 2010.

Plate 53. Summary of runoff water quality conditions monitored in the north tributary inflow to Standing Bear Reservoir at monitoring site STBNFNRT1 during the period 2006 through 2010**.**

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Turbidity (NTUs)	1	13	178	36	23	1766	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	16	-----	0.16	0.00	0.56	(1)	(1)	(1)
Kjeldahl N, Total (mg/l)	0.1	16	1.7	1.3	0.7	6.6	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	16	-----	0.11	n.d.	0.34	100(4)	0	0%
Phosphorus, Total (mg/l)	0.02	16	0.29	0.26	0.03	0.69	-----	-----	-----
Suspended Solids, Total (mg/l)	4	15	88	61	18	324	-----	-----	-----
Acetochlor, Total (ug/l)[C]	0.05	10	-----	n.d.	n.d.	0.40	-----	-----	-----
Alachlor, Total (ug/l)[C]	0.05	6	-----	n.d.	n.d.	0.06	760(2), 76(3)	0	0%
Atrazine, Total (ug/l)[C]	0.05	16	-----	0.05	n.d.	0.60	330(2), 12(3)	0	0%
Metolachlor, Total (ug/l)[C]	0.05	16	-----	n.d.	n.d.	0.20	390(2), 100(3)	0	0%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Total ammonia criteria pH and temperature dependent. Since pH was not measured criteria are not calculated.
(2) Acute criterion for aquatic life.
(3) Chronic criterion for aquatic life.
(4) Agricultural criteria for surface waters.
(C) Immunoassay analysis.

Plate 54. Summary of runoff water quality conditions monitored in the south tributary inflow to Standing Bear Reservoir at monitoring site STBNFSTH1 during the period 2006 through 2010.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Turbidity (NTUs)	1	13	564	125	24	5564	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	16	-----	0.15	n.d.	0.36	(1)	(1)	(1)
Kjeldahl N, Total (mg/l)	0.1	16	1.8	1.5	0.7	7.1	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	16	0.31	0.34	0.05	0.70	100(4)	0	0%
Phosphorus, Total (mg/l)	0.02	16	0.47	0.42	0.06	1.23	-----	-----	-----
Suspended Solids, Total (mg/l)	4	15	220	148	41	450	-----	-----	-----
Acetochlor, Total (ug/l)[C]	0.05	10	-----	n.d.	n.d.	0.80	-----	-----	-----
Alachlor, Total (ug/l)[C]	0.05	6	-----	n.d.	n.d.	0.11	760(2), 76(3)	0	0%
Atrazine, Total (ug/l)[C]	0.05	16	-----	0.03	n.d.	0.73	330(2), 12(3)	0	0%
Metolachlor, Total (ug/l)[C]	0.05	16	-----	n.d.	n.d.	0.20	390(2), 100(3)	0	0%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Total ammonia criteria pH and temperature dependent. Since pH was not measured criteria are not calculated.
(2) Acute criterion for aquatic life.
(3) Chronic criterion for aquatic life.
(4) Agricultural criteria for surface waters.
(C) Immunoassay analysis.

Plate 55. Summary of water quality conditions monitored in Wehrspann Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site WEHLKND1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	25	1094.9	1095.9	1088.5	1097.4	-----	-----	-----
Water Temperature (°C)	0.1	323	22.8	22.8	13.7	31.0	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	323	6.4	7.0	0.2	17.9	≥ 5[2]	99	31%
Dissolved Oxygen (% Sat.)	0.1	314	77.0	86.1	1.9	238.4	-----	-----	-----
Specific Conductance (umho/cm)	1	314	415	416	231	569	2,000[3]	0	0%
pH (S.U.)	0.1	314	8.0	8.1	6.8	9.5	≥6.5 & ≤9.0[1]	0,7	0,2%
Turbidity (NTUs)	1	313	25	19	1	199	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	314	267	271	-107	436	-----	-----	-----
Secchi Depth (in.)	1	25	28	24	13	62	-----	-----	-----
Alkalinity, Total (mg/l)	7	50	128	123	93	194	20[1]	0	0%
Ammonia, Total (mg/l)	0.01	50	-----	0.12	n.d.	2.64	6.95[4,5], 1.23[4,6]	0, 4	0%, 8%
Chlorophyll *a* (ug/l) – Field Probe	1	249	34	20	0	228	10[7]	209	84%
Chlorophyll *a* (ug/l) – Lab Determined	1	25	47	35	1	130	10[7]	18	72%
Hardness, Total (mg/l)	0.4	5	116.6	118.0	94.0	134.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	50	1.4	1.4	0.1	4.0	-----	-----	-----
Nitrogen, Total (mg/)	0.1	50	1.5	1.4	0.1	4.0	1[7]	36	72%
Nitrate-Nitrite N, Total (mg/l)	0.02	50	-----	n.d.	0.00	0.66	100[3]	0	0%
Phosphorus, Total (mg/l)	0.10	50	0.1	0.1	0.0	0.4	0.05[7]	45	90%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	-----	0.02	n.d.	0.17	-----	-----	-----
Suspended Solids, Total (mg/l)	4	49	14	12	n.d.	29	-----	-----	-----
Aluminum, Dissolved (ug/l)	25	5	-----	n.d.	n.d.	5	750[5], 87[6]	0	0%
Antimony, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	7.0	88[5], 30[6]	0	0%
Arsenic, Dissolved (ug/l)	2	5	-----	6	5	11	340[5], 16.7[8]	0	0%
Beryllium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	130[5], 5.3[6]	0	0%
Cadmium, Dissolved (ug/l)	0.2	5	-----	n.d.	n.d.	n.d.	6.9[5], 0.3[6]	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	10.00	678[5], 88[6]	0	0%
Copper, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	16[5], 10[6]	0	0%
Lead, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	77[5], 3.0[6]	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4[5]	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77[6]	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	539[5], 60[6]	0	0%
Selenium, Total (ug/l)	1	5	-----	1	n.d.	2	20[3,5], 5[6]	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	1	4.6[5]	0	0%
Thallium (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	1,400[5], 6.3[8]	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	135[5,6]	0	0%
Microcystin, Total (ug/l)	0.05	24	-----	n.d.	n.d.	0.54	20[9]	0	0%
Acetochlor, Total (ug/l)[C]	0.05	15	0.44	0.30	n.d.	1.80	-----	-----	-----
Alachlor, Total (ug/l)[C]	0.05	10	-----	n.d.	n.d.	0.11	760[5], 76[6]	0	0%
Atrazine, Total (ug/l)[C]	0.05	25	0.93	1.00	0.20	1.90	330[5], 12[6]	0	0%
Metolachlor, Total (ug/l)[C]	0.05	25	-----	0.06	n.d.	1.20	390[5], 100[6]	0	0%
Pesticide Scan (ug/l)[D]	0.05						-----	-----	-----
Atrazine		5	-----	0.2	n.d.	0.8	330[5], 12[6]	0	0%
Profluralin		1	0.33	0.33	0.33	0.33	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l microcystins in recreation water for impairment assessment.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 56. Summary of water quality conditions monitored in Wehrspann Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site WEHLKML1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	24	1094.9	1095.9	1088.5	1097.4	-----	-----	-----
Water Temperature (°C)	0.1	289	22.5	23.0	13.1	30.8	32[(1)]	0	0%
Dissolved Oxygen (mg/l)	0.1	288	6.8	7.4	0.2	13.9	≥ 5[(2)]	68	24%
Dissolved Oxygen (% Sat.)	0.1	276	81.0	89.8	2.1	183.0	-----	-----	-----
Specific Conductance (umho/cm)	1	277	420	418	248	547	2,000[(3)]	0	0%
pH (S.U.)	0.1	261	8.1	8.2	7.0	9.4	≥6.5 & ≤9.0[(1)]	0	0%
Turbidity (NTUs)	1	276	22	18	1	330	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	277	297	299	-74	435	-----	-----	-----
Secchi Depth (in.)	1	25	27	23	11	56	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	236	30	18	1	212	10[(4)]	189	80%

n.d. = Not detected.

[(A)] Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

[(B)] [(1)] General criteria for aquatic life.
[(2)] Use-specific criteria for aquatic life.
[(3)] Agricultural criteria for surface waters.
[(4)] Nutrient criteria for aquatic life.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria

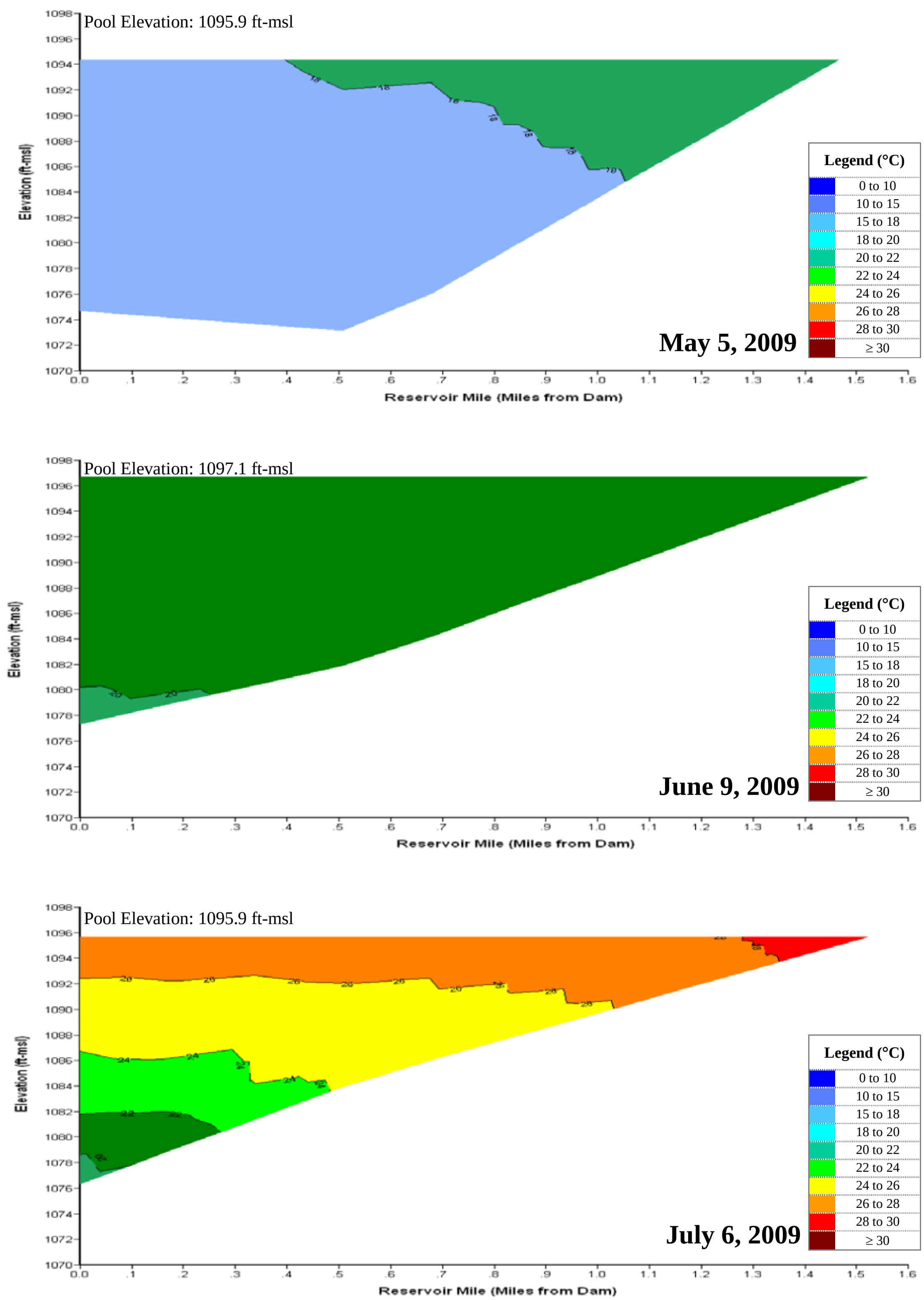
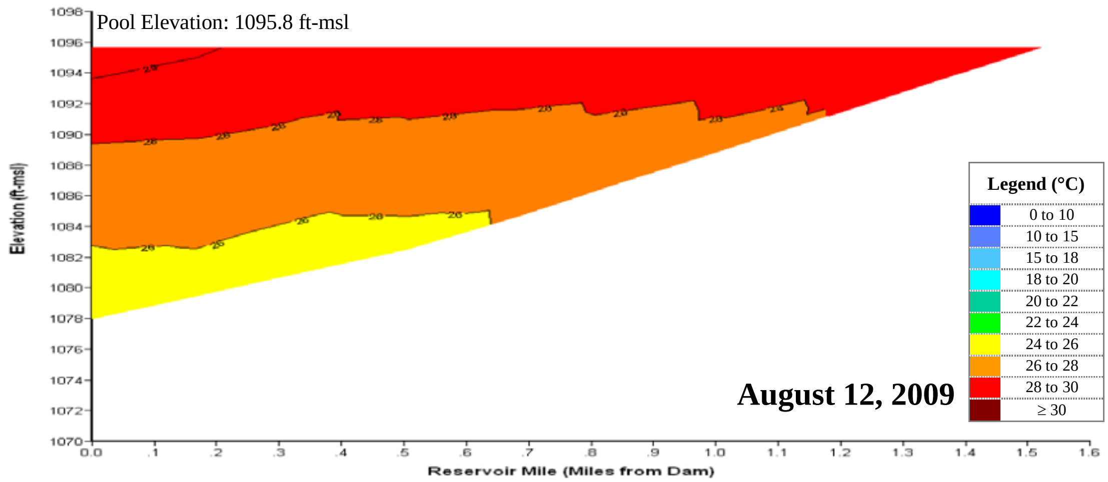


Plate 57. Longitudinal water temperature contour plots of Wehrspann Reservoir based on depth-profile water temperatures (°C) measured at sites WEHLKND1 and WEHLKML1 in 2009.



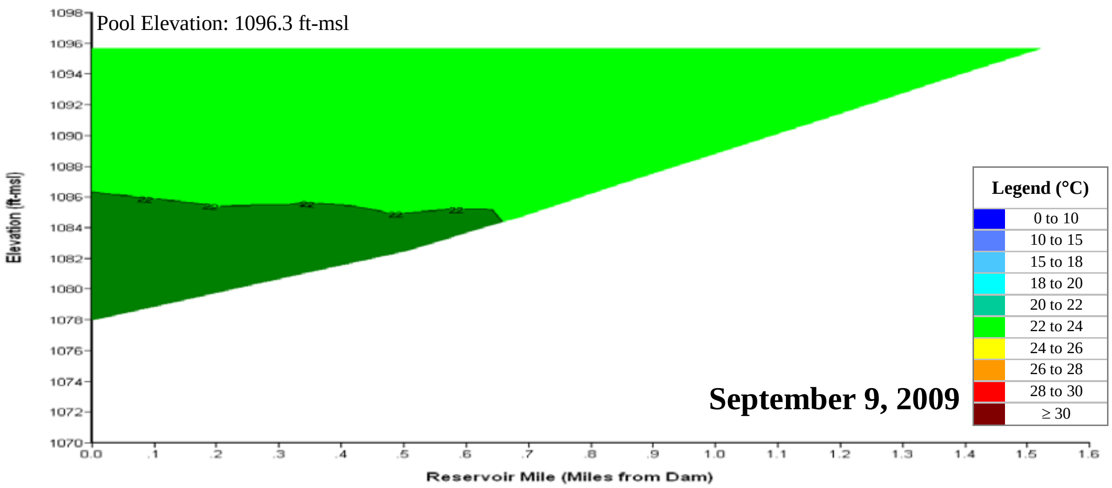


Plate 57. (Continued).

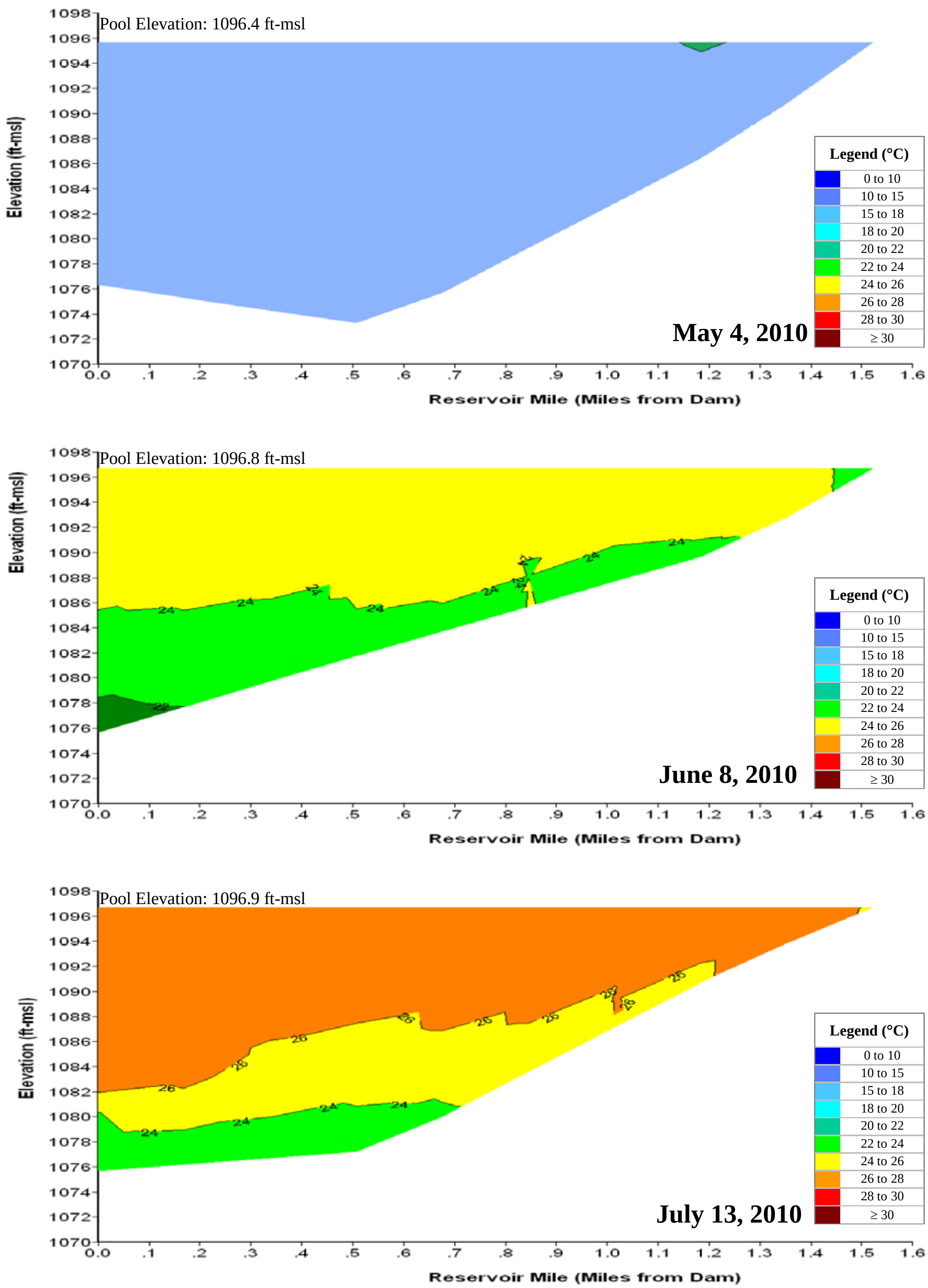
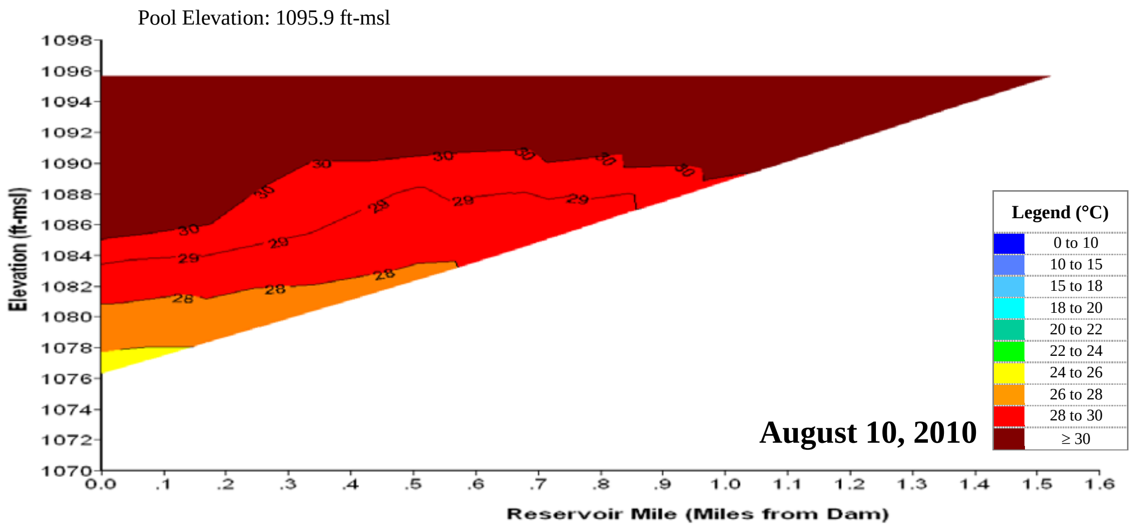


Plate 58. Longitudinal water temperature contour plots of Wehrspann Reservoir based on depth-profile water temperatures (°C) measured at sites WEHLKND1, WEHLKML1, and WEHLKUP1 in 2010.



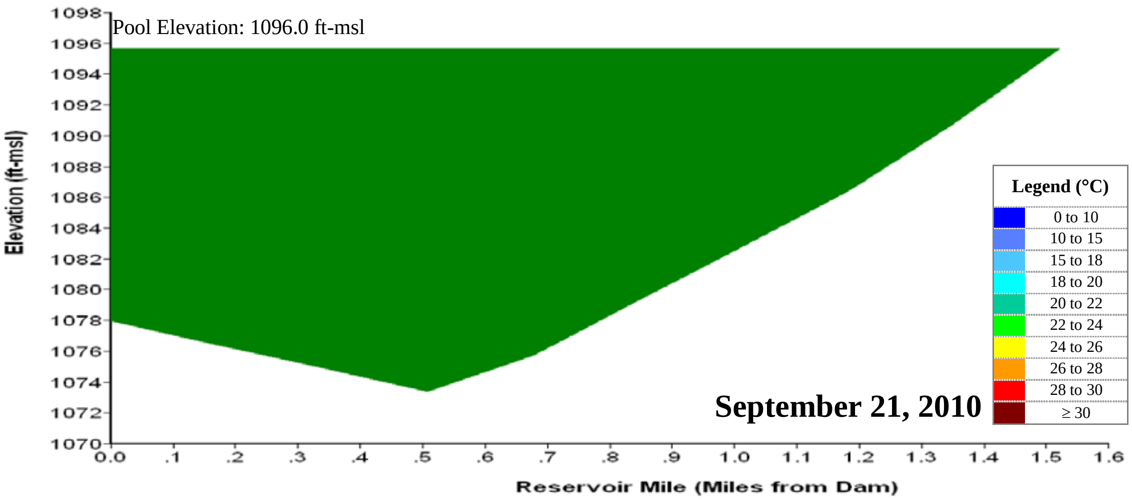


Plate 58. (Continued).

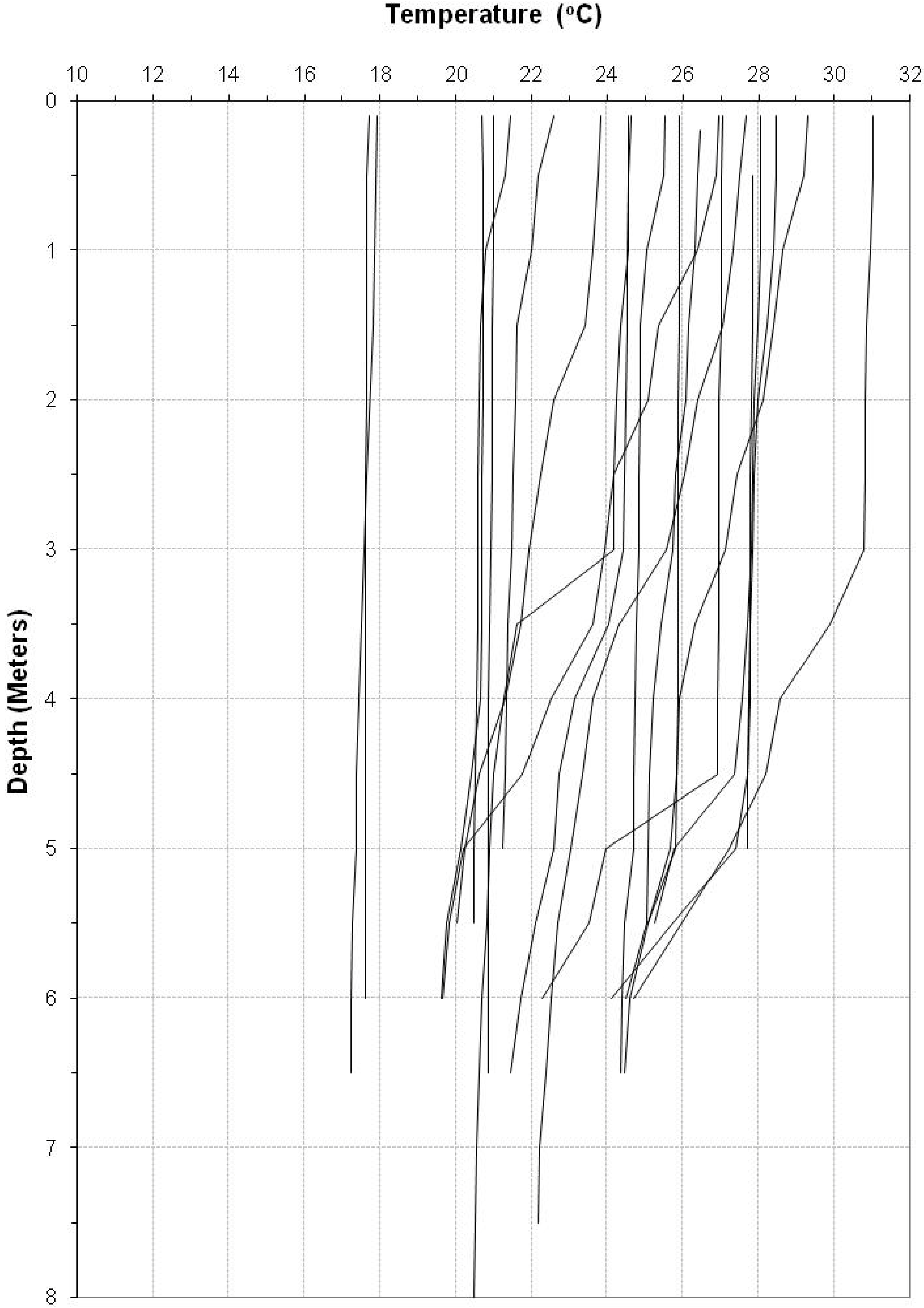
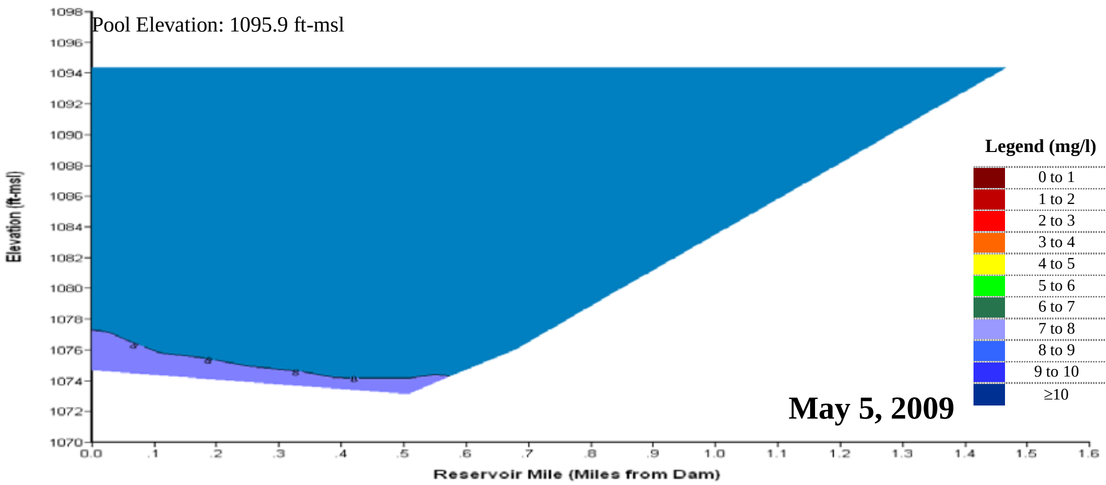
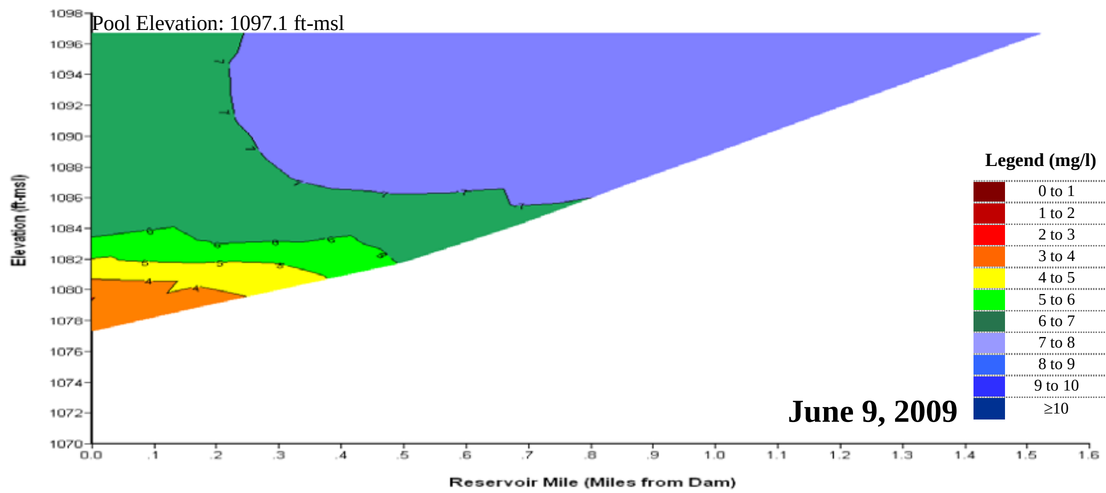


Plate 59. Temperature depth profiles for Wehrspann Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., WEHLKND1) during the summer over the 5-year period of 2006 through 2010.





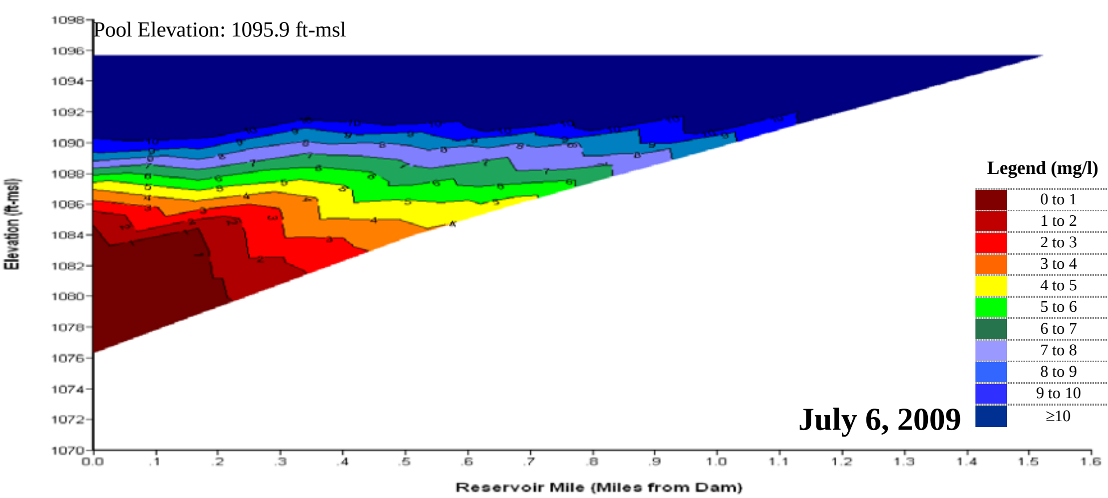
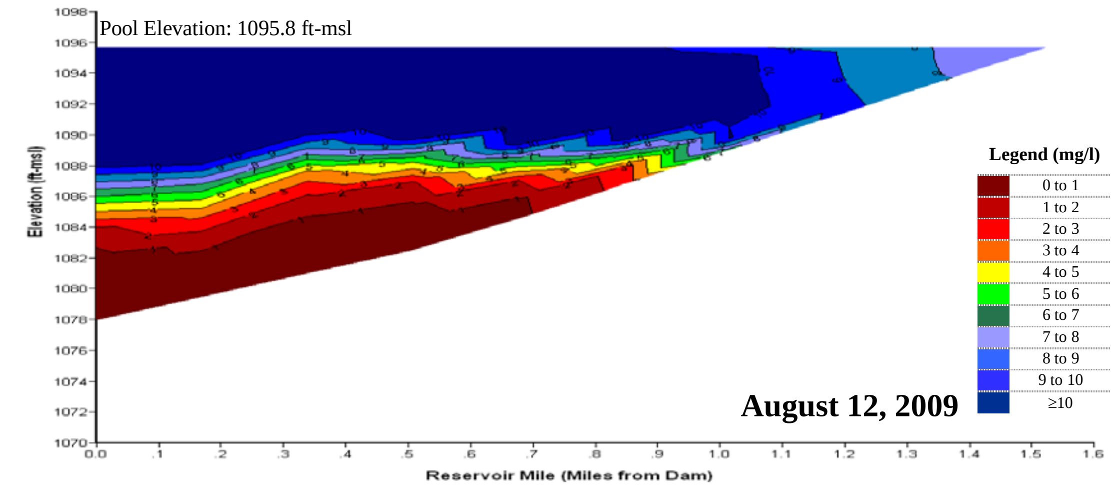


Plate 60. Longitudinal dissolved oxygen contour plots of Wehrspann Reservoir based on depth-profile dissolved oxygen concentrations (mg/l) measured at sites WEHLKND1 and WEHLKML1 in 2009.



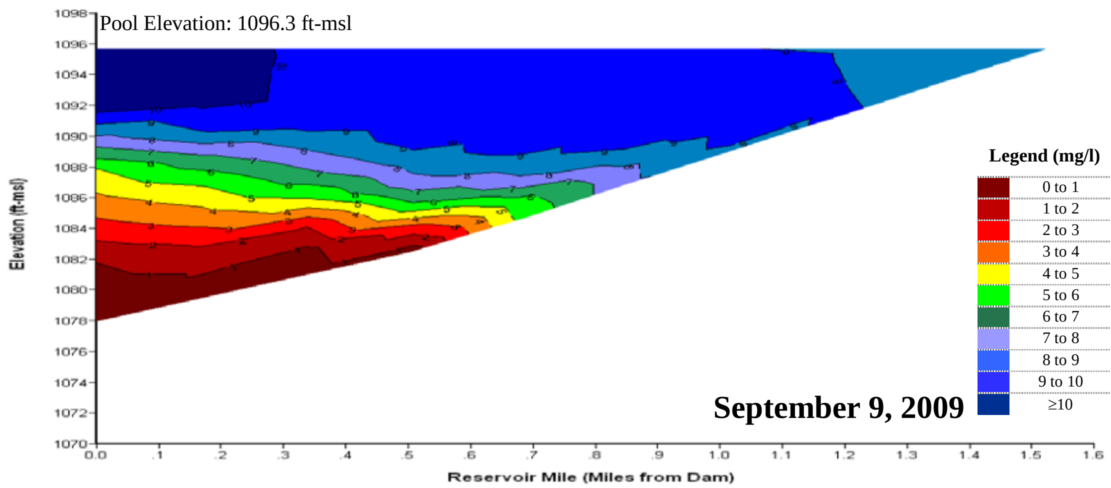


Plate 60. (Continued).

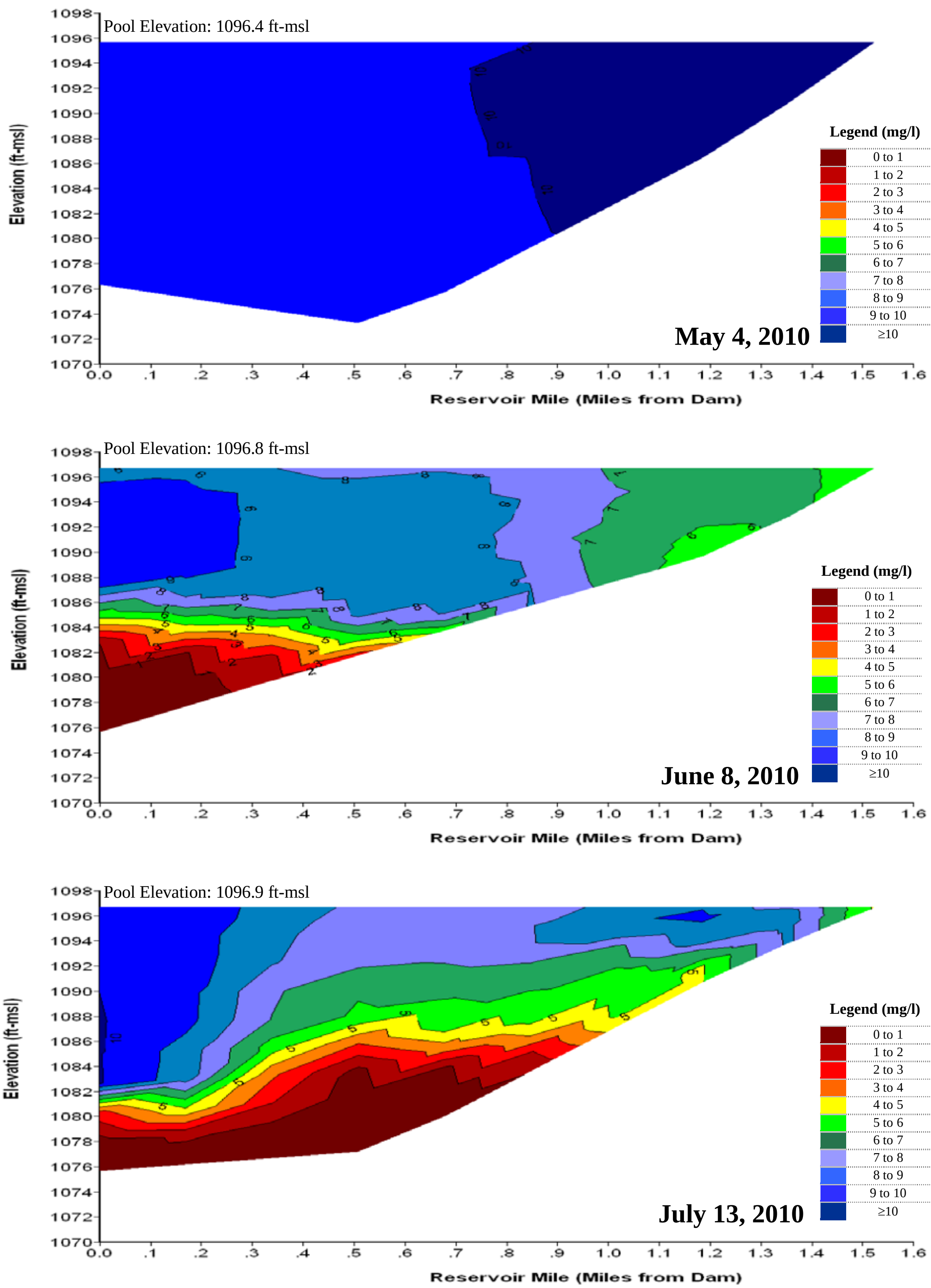
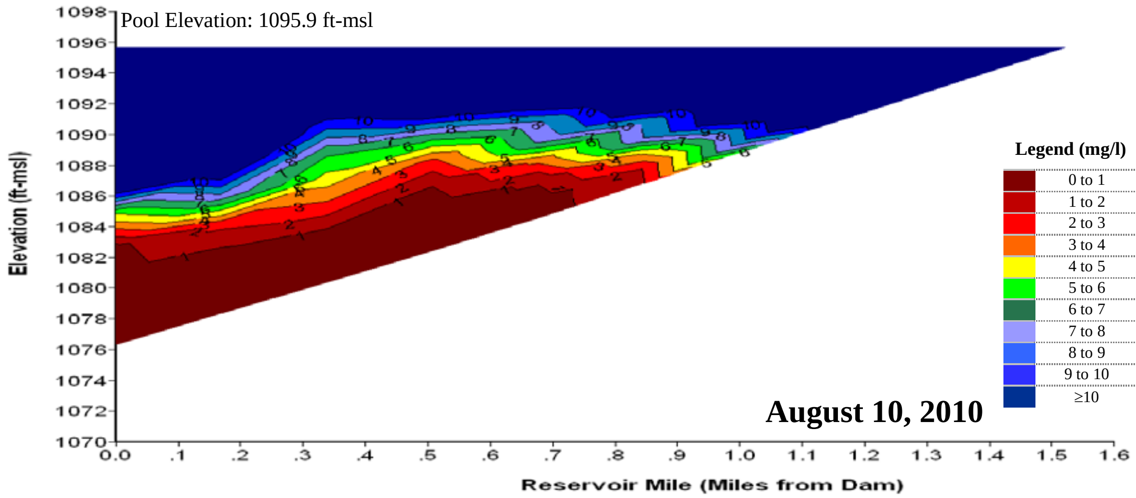


Plate 61. Longitudinal dissolved oxygen contour plots of Wehrspann Reservoir based on depth-profile dissolved oxygen concentrations (mg/l) measured at sites WEHLKND1, WEHLKML1, and WEHLKUP1 in 2010.



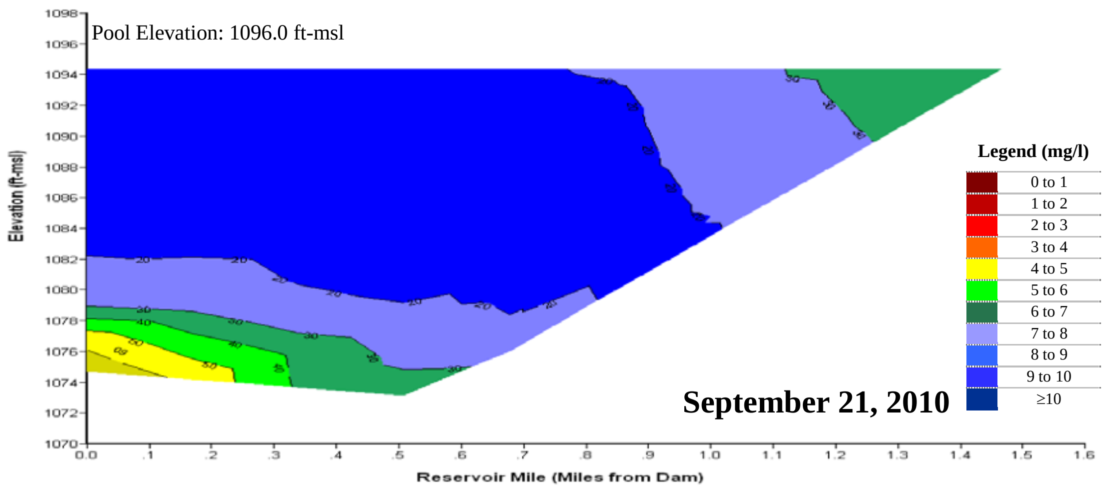


Plate 61. (Continued).

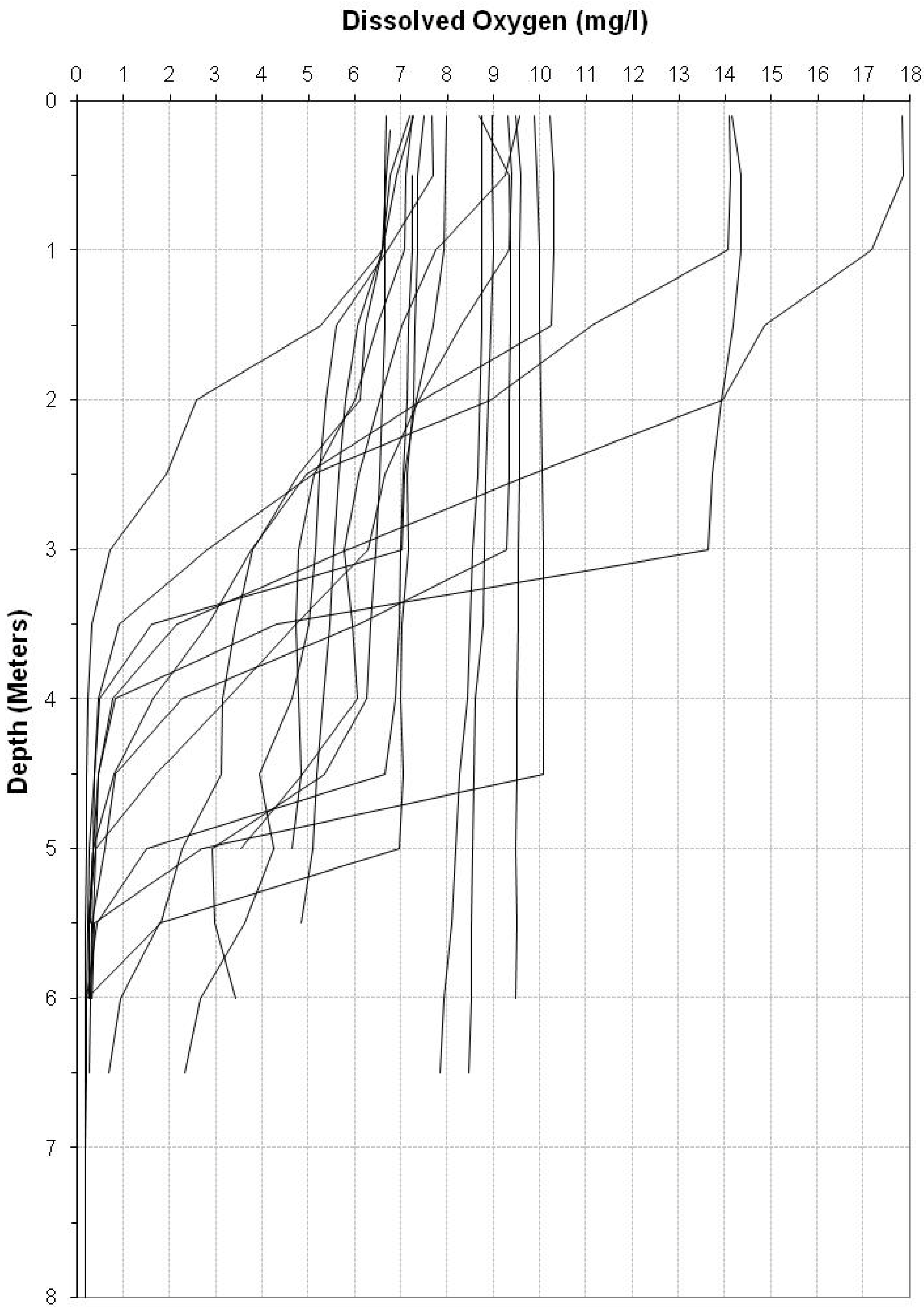


Plate 62. Dissolved oxygen depth profiles for Wehrspann Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., WEHLKND1) during the summer over the 5-year period of 2006 through 2010.

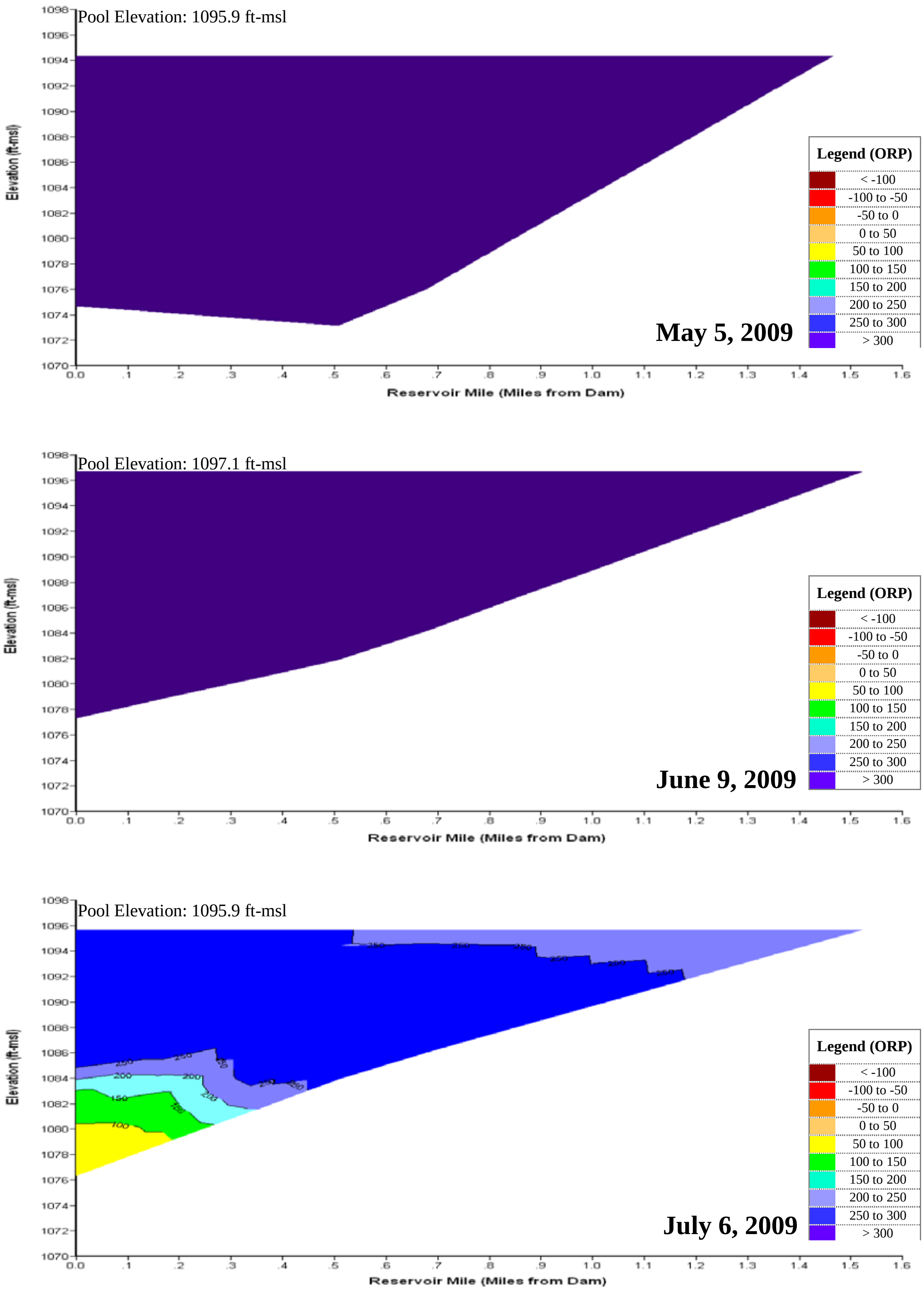
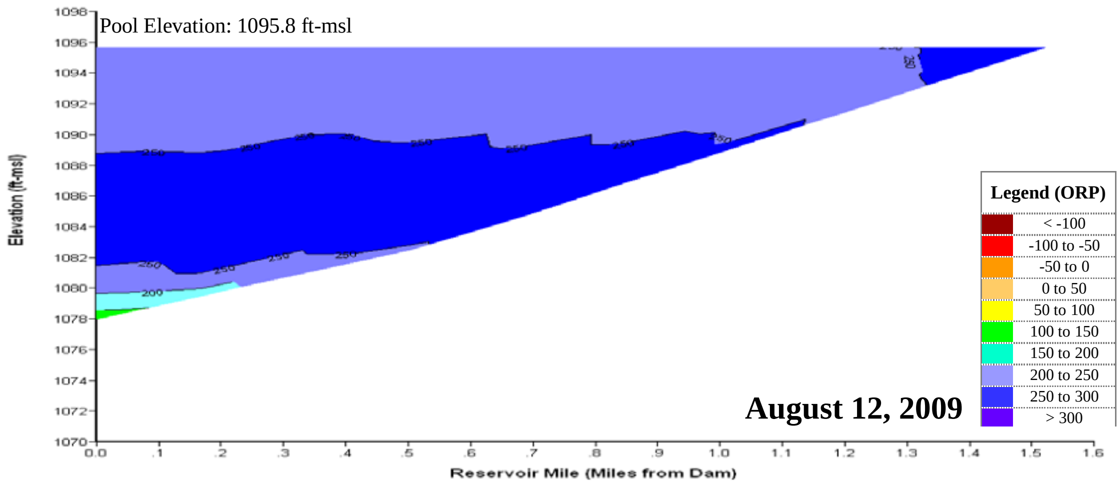


Plate 63. Longitudinal oxidation-reduction potential contour plots of Wehrspann Reservoir based on depth-profile ORP levels (mV) measured at sites WEHLKND1 and WEHLKML1 in 2009.



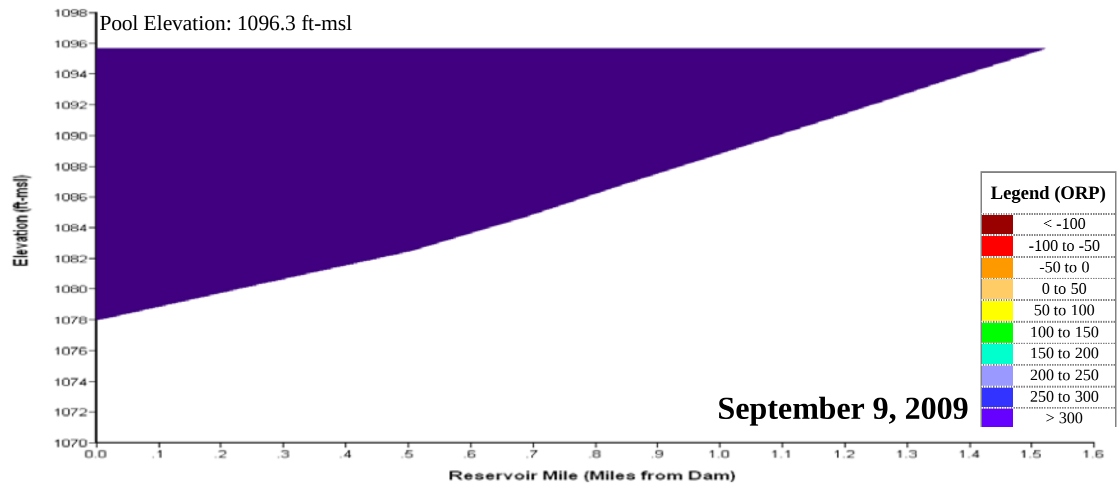


Plate 63. (Continued).

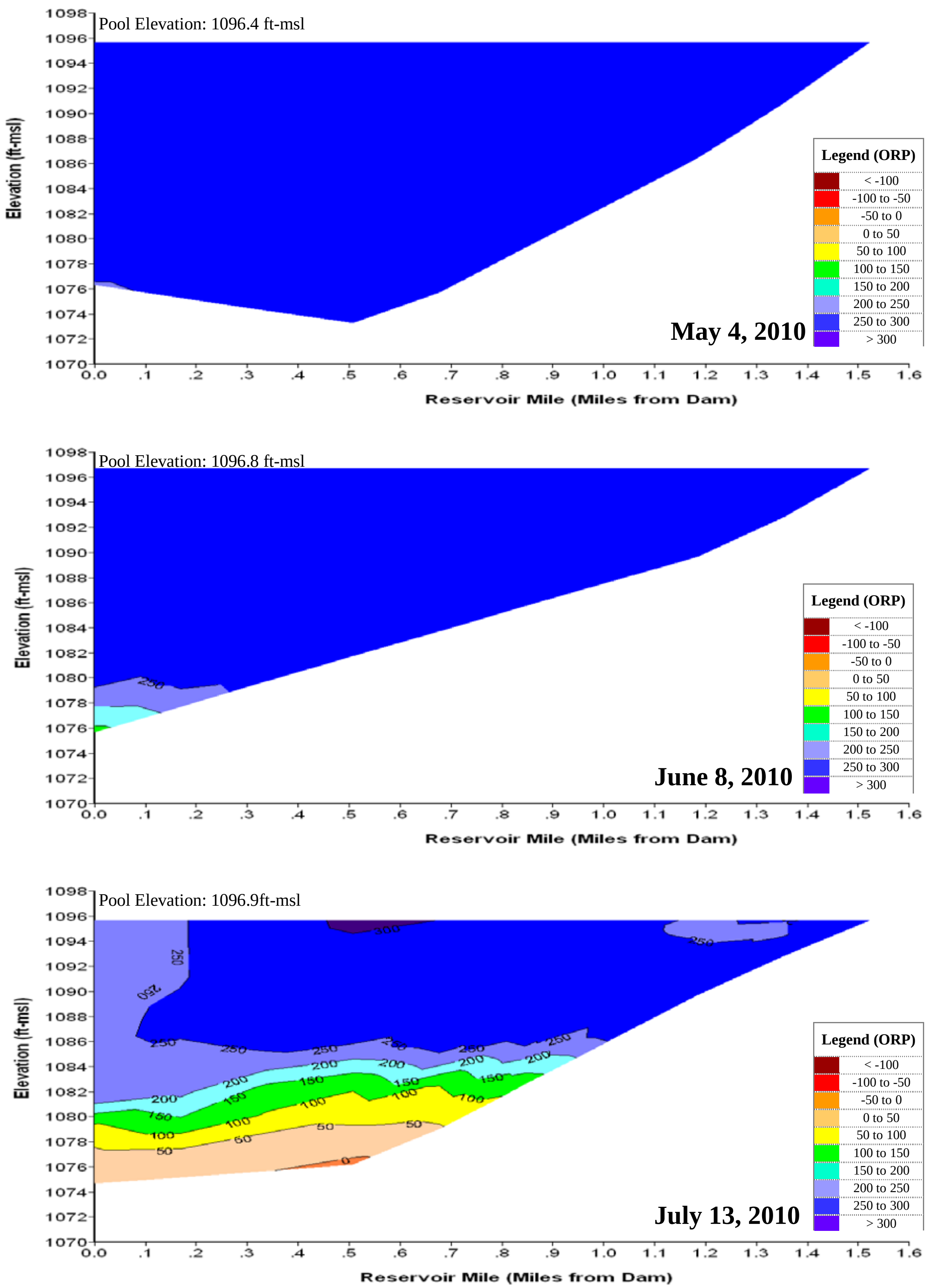
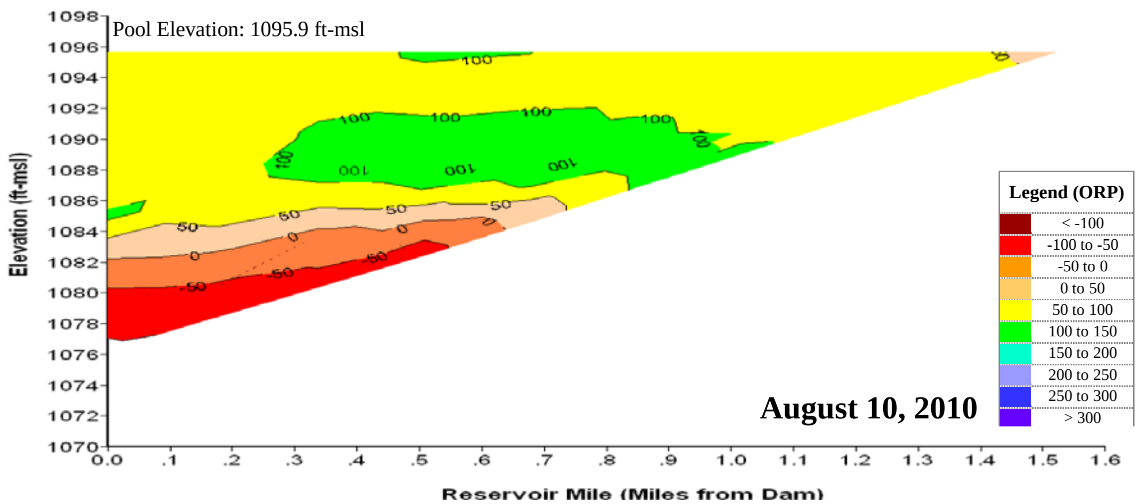


Plate 64. Longitudinal oxidation-reduction potential contour plots of Wehrspann Reservoir based on depth-profile ORP levels (mV) measured at sites WEHLKND1, WEHLKML1, and WEHLKUP1 in 2010.



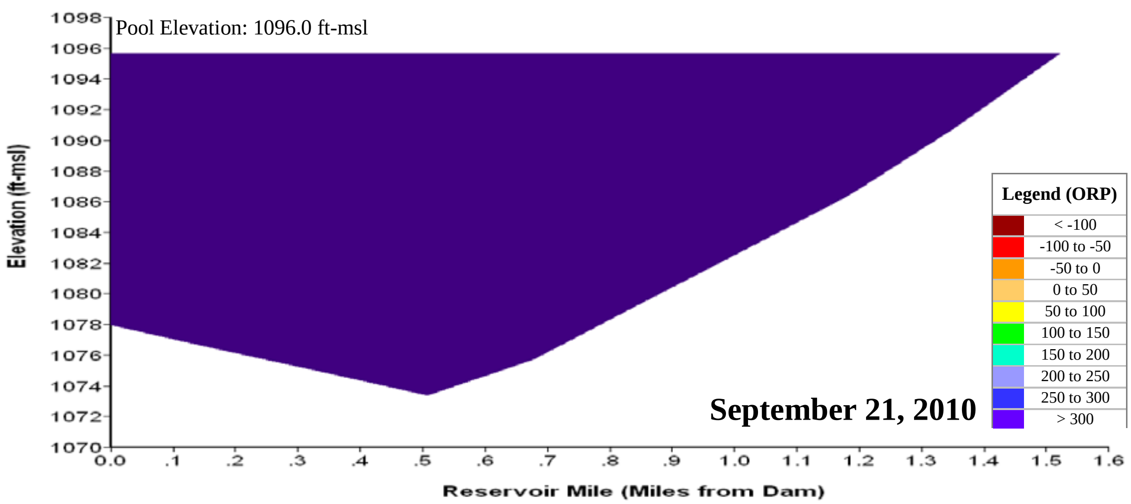


Plate 64. (Continued).

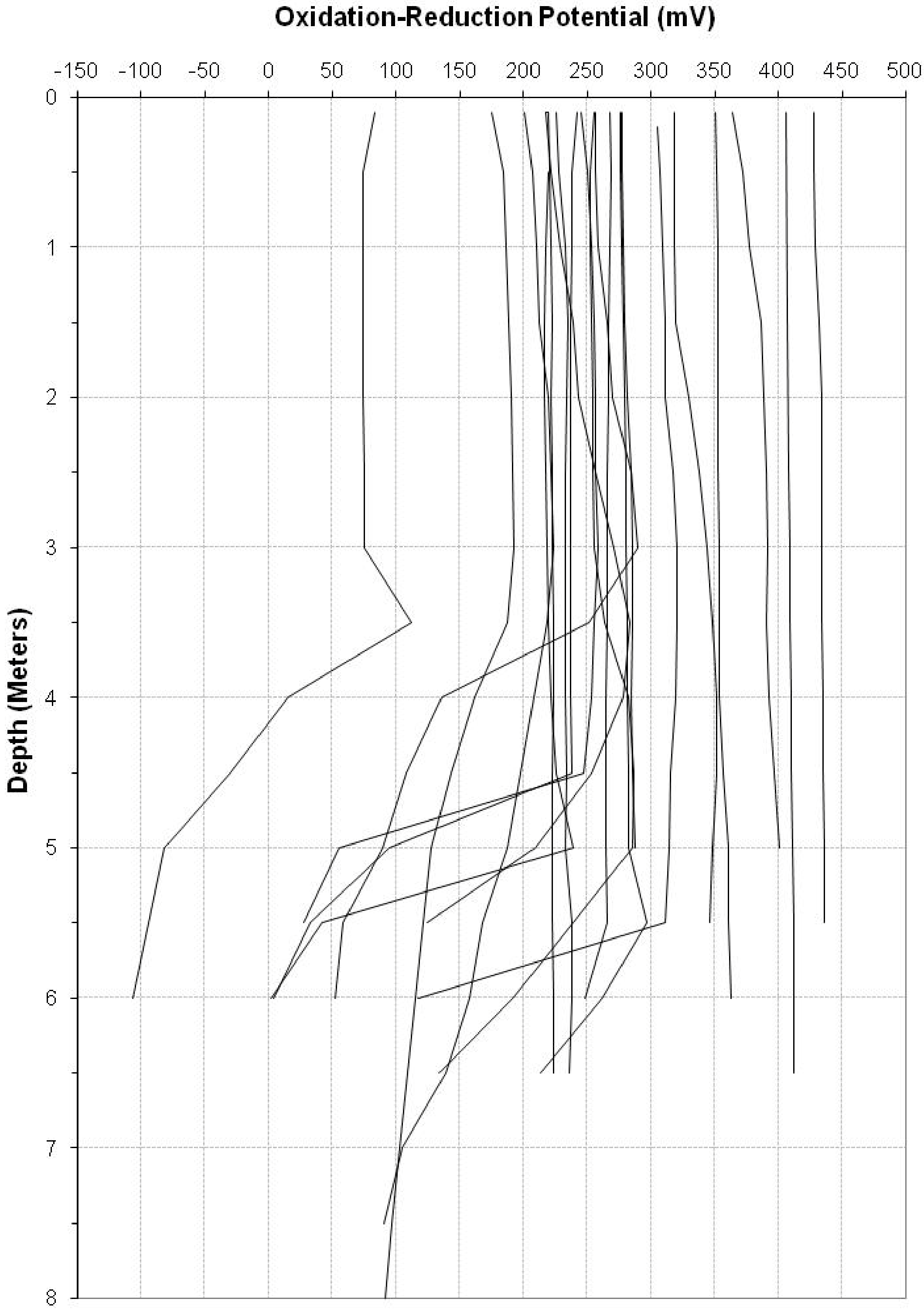
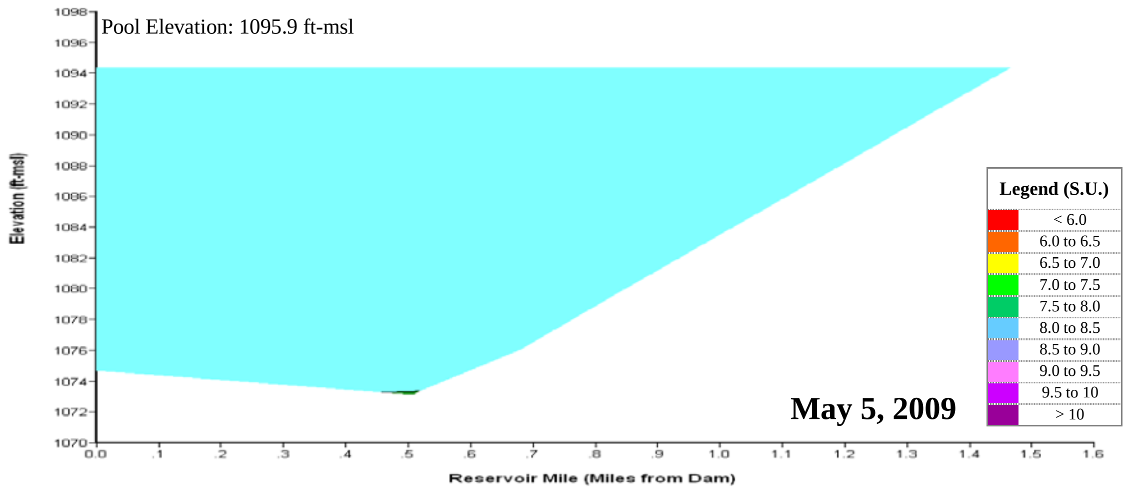
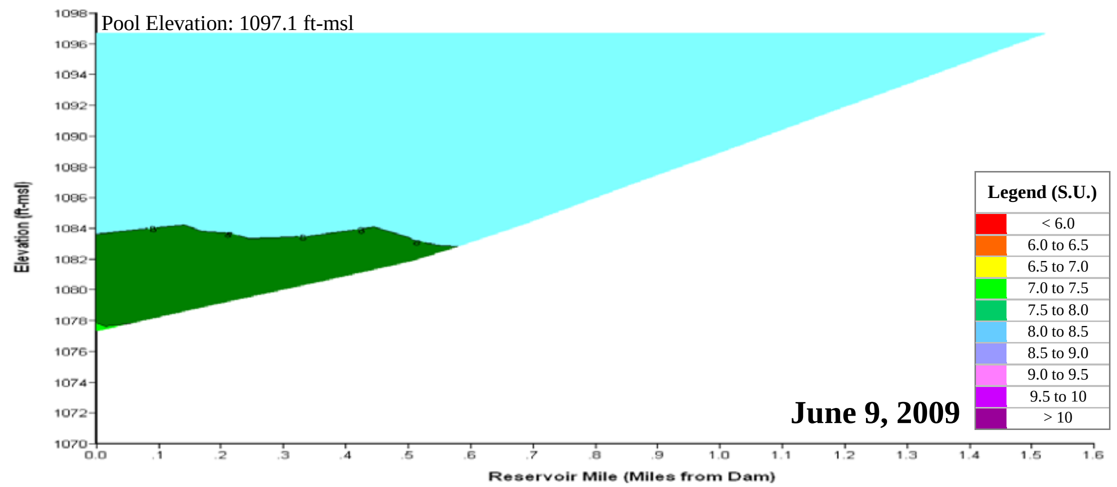


Plate 65. Oxidation-reduction potential depth profiles for Wehrspann Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., WEHLKND1) during the summer over the 5-year period of 2006 through 2010.





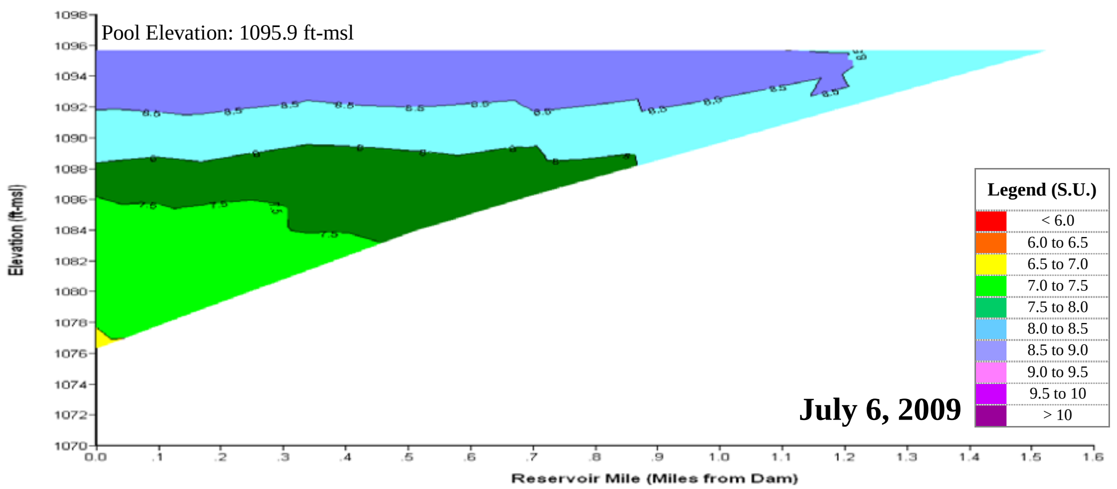
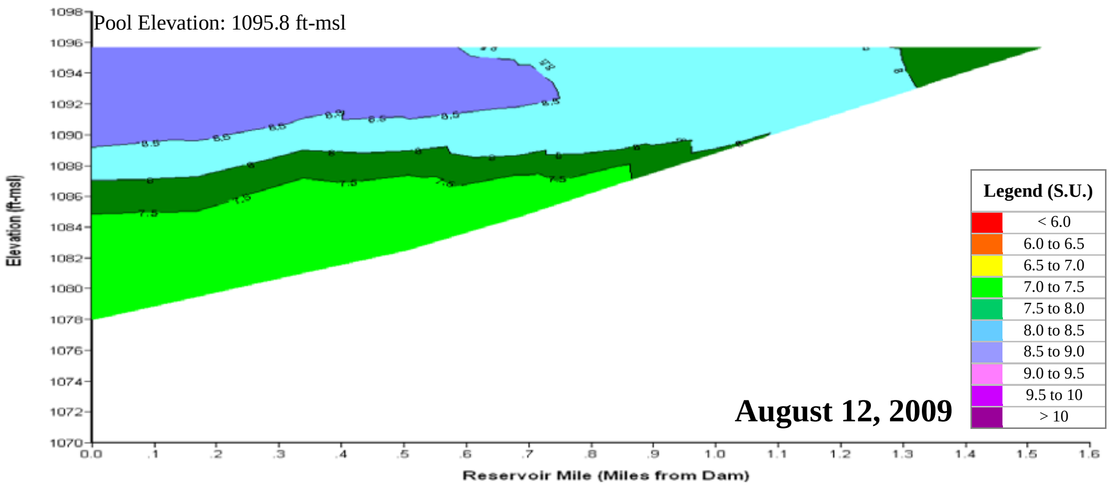


Plate 66. Longitudinal pH contour plots of Wehrspann Reservoir based on depth-profile pH levels (S.U.) measured at sites WEHLKND1 and WEHLKML1 in 2009.



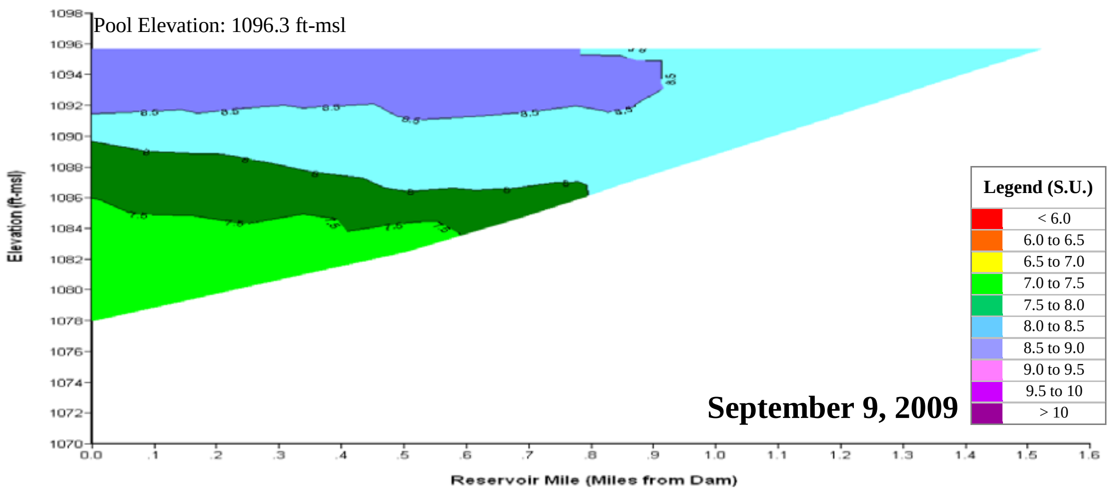


Plate 66. (Continued).

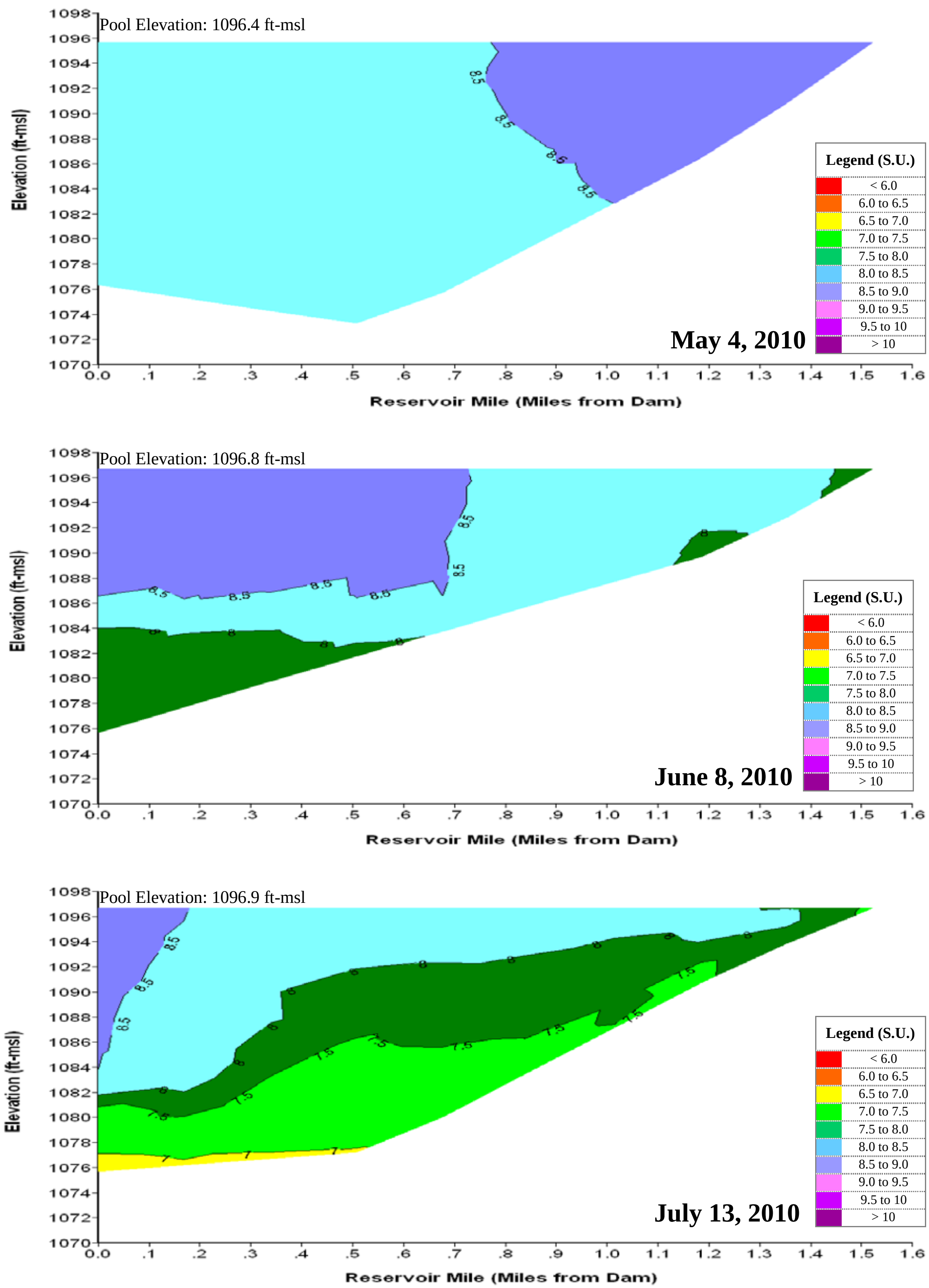
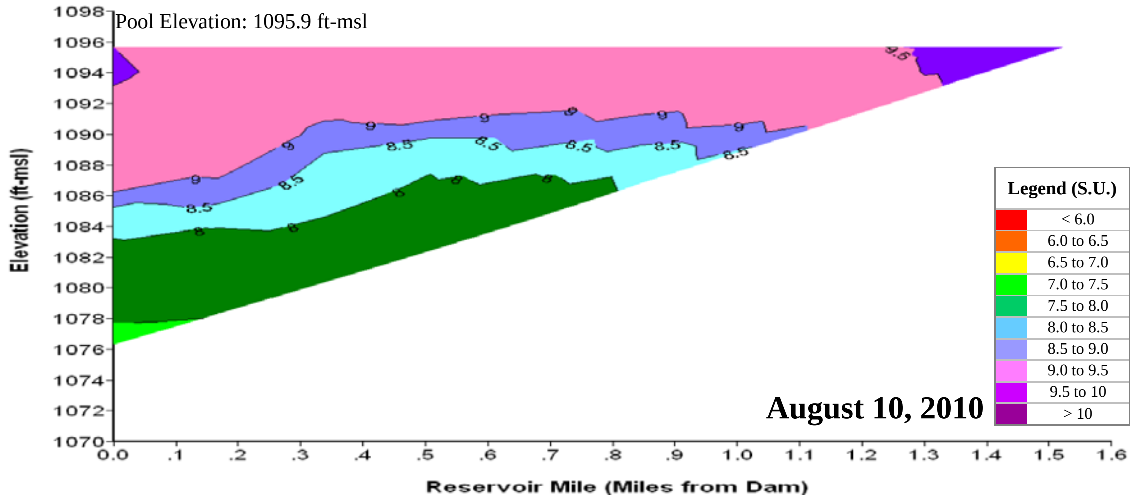


Plate 67. Longitudinal pH contour plots of Wehrspann Reservoir based on depth-profile pH levels (S.U.) measured at sites WEHLKND1, WEHLKML1, and WEHLKUP1 in 2010.



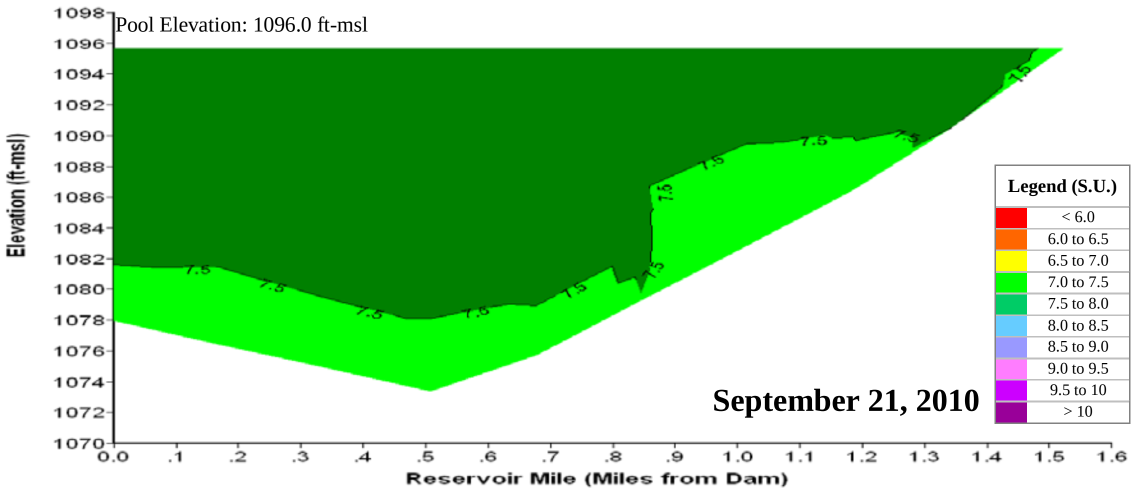


Plate 67. (Continued).

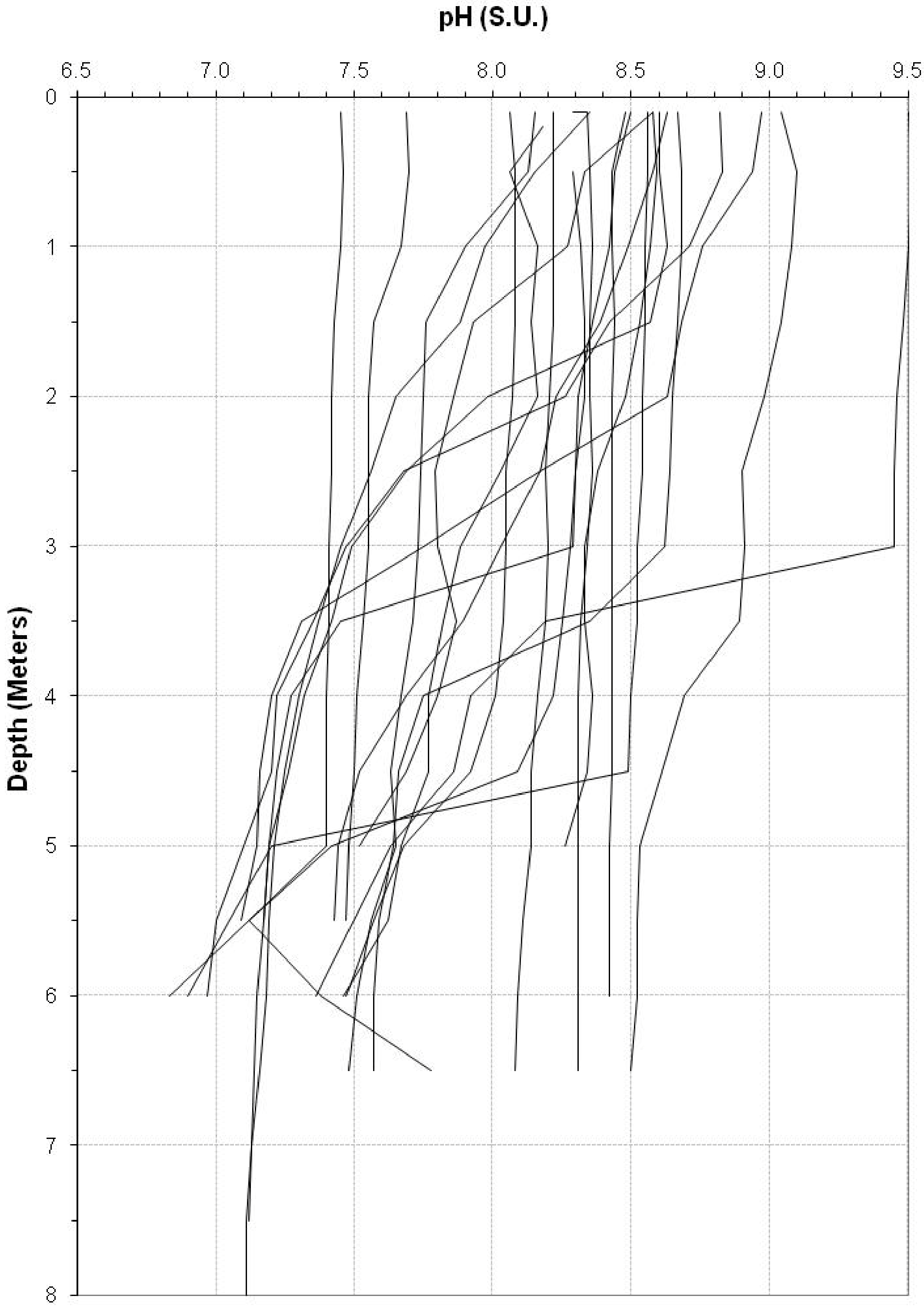


Plate 68. pH depth profiles for Wehrspann Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., WEHLKND1) during the summer over the 5-year period of 2006 through 2010.

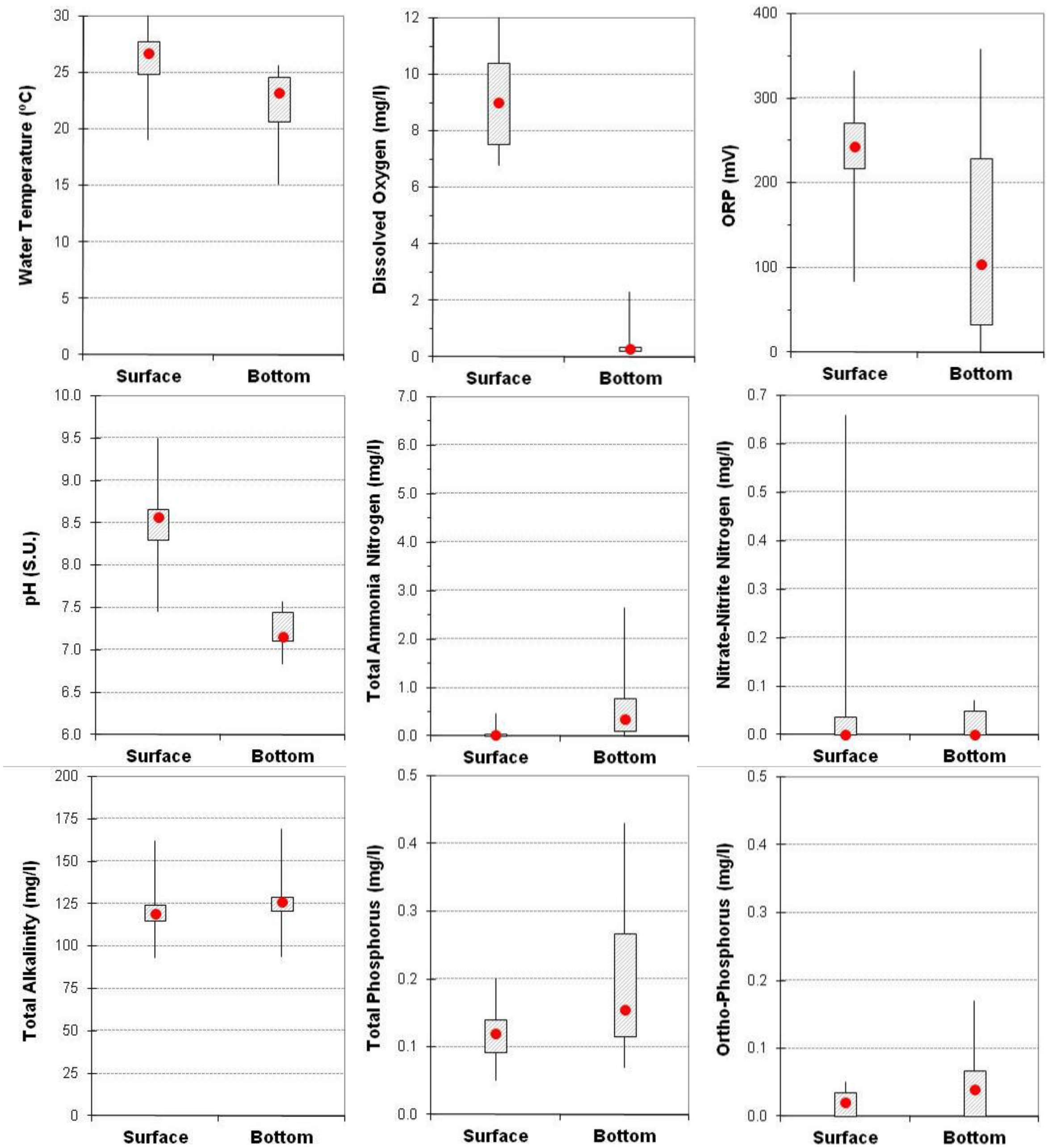
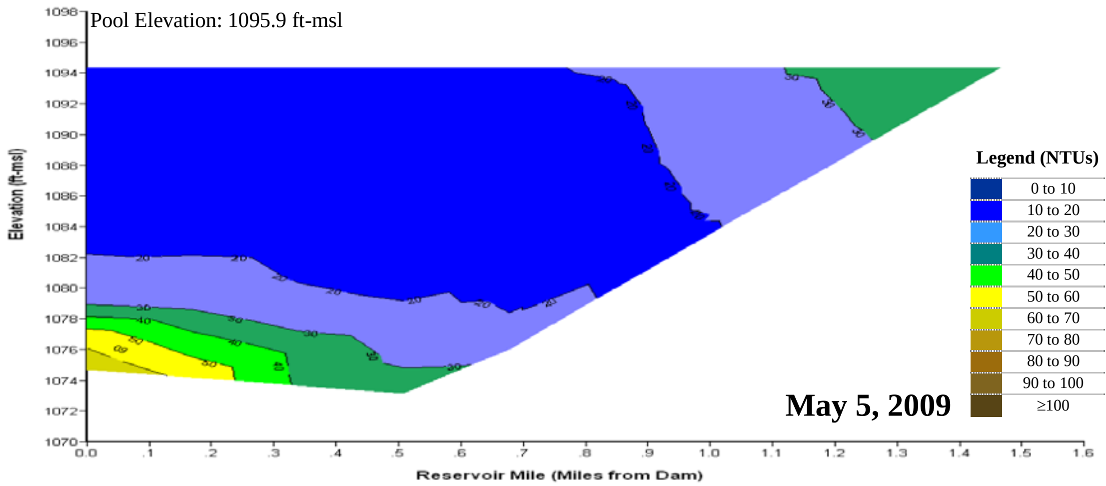
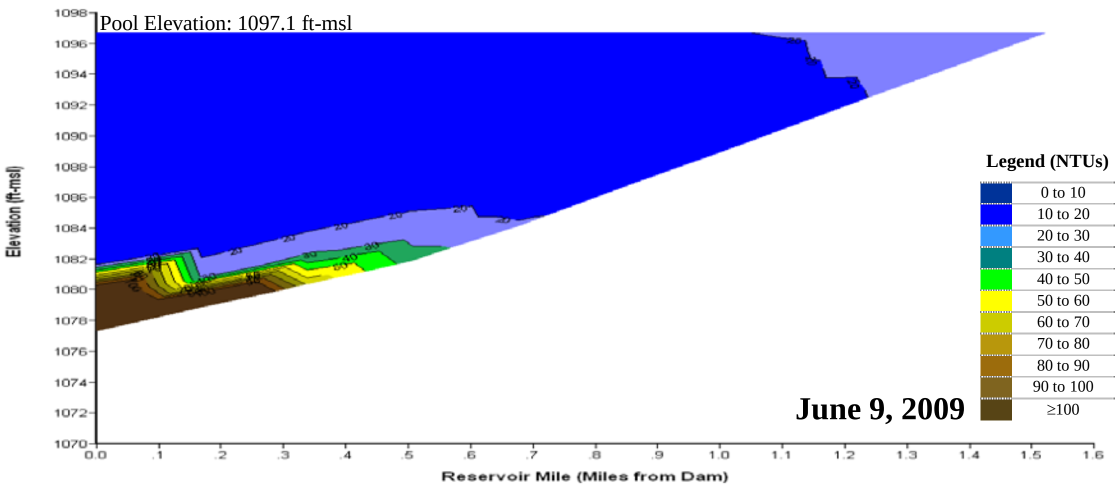


Plate 69. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, alkalinity, total ammonia nitrogen, nitrate-nitrite nitrogen, total phosphorus, and ortho-phosphorus measured in Wehrspann Reservoir during the 5-year period 2006 through 2010. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)





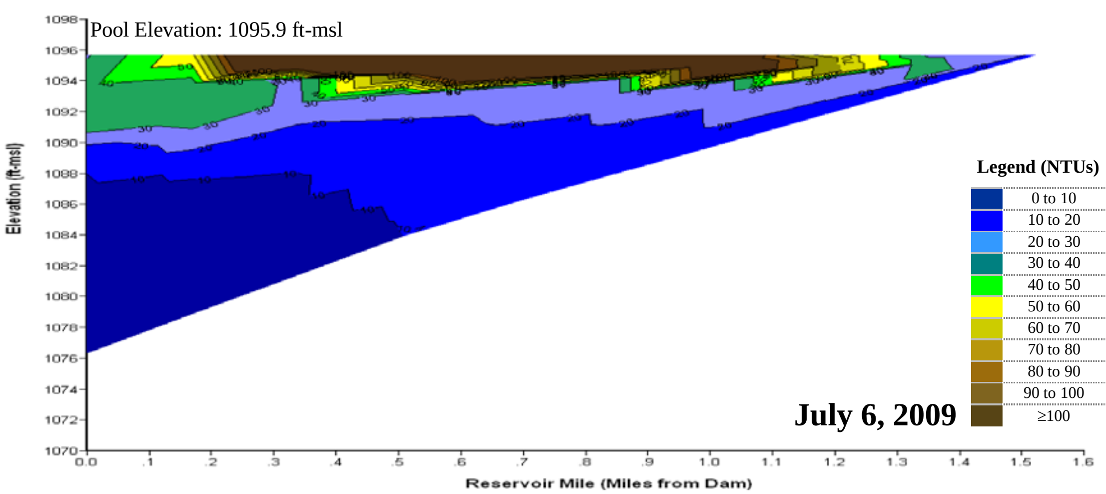
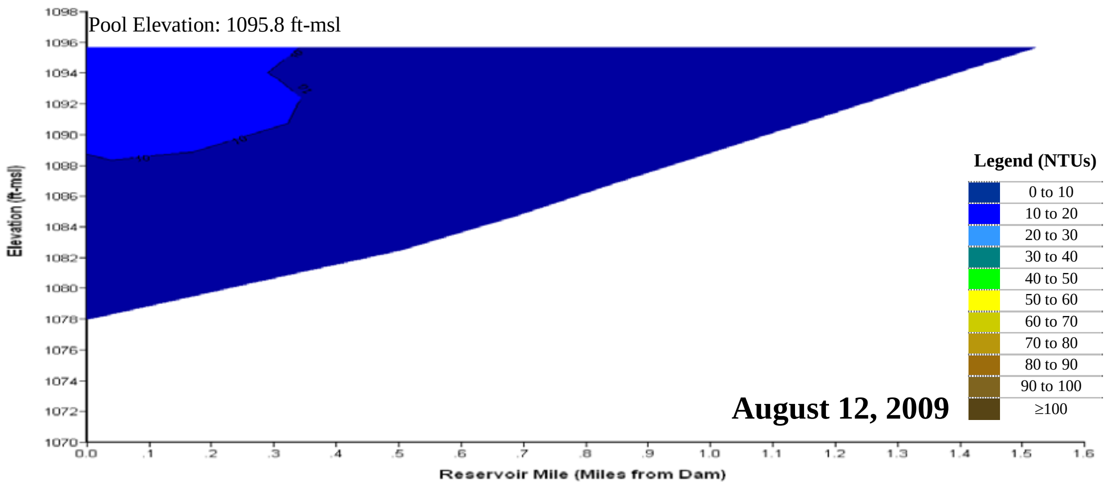


Plate 70. Longitudinal turbidity contour plots of Wehrspann Reservoir based on depth-profile turbidity levels (NTU) measured at sites WEHLKND1 and WEHLKML1 in 2009.



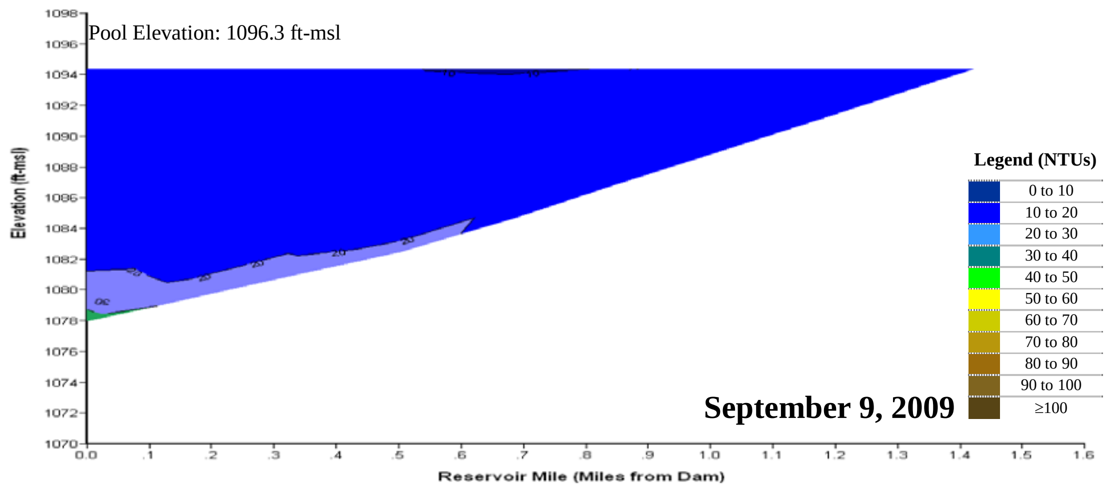


Plate 70. (Continued).

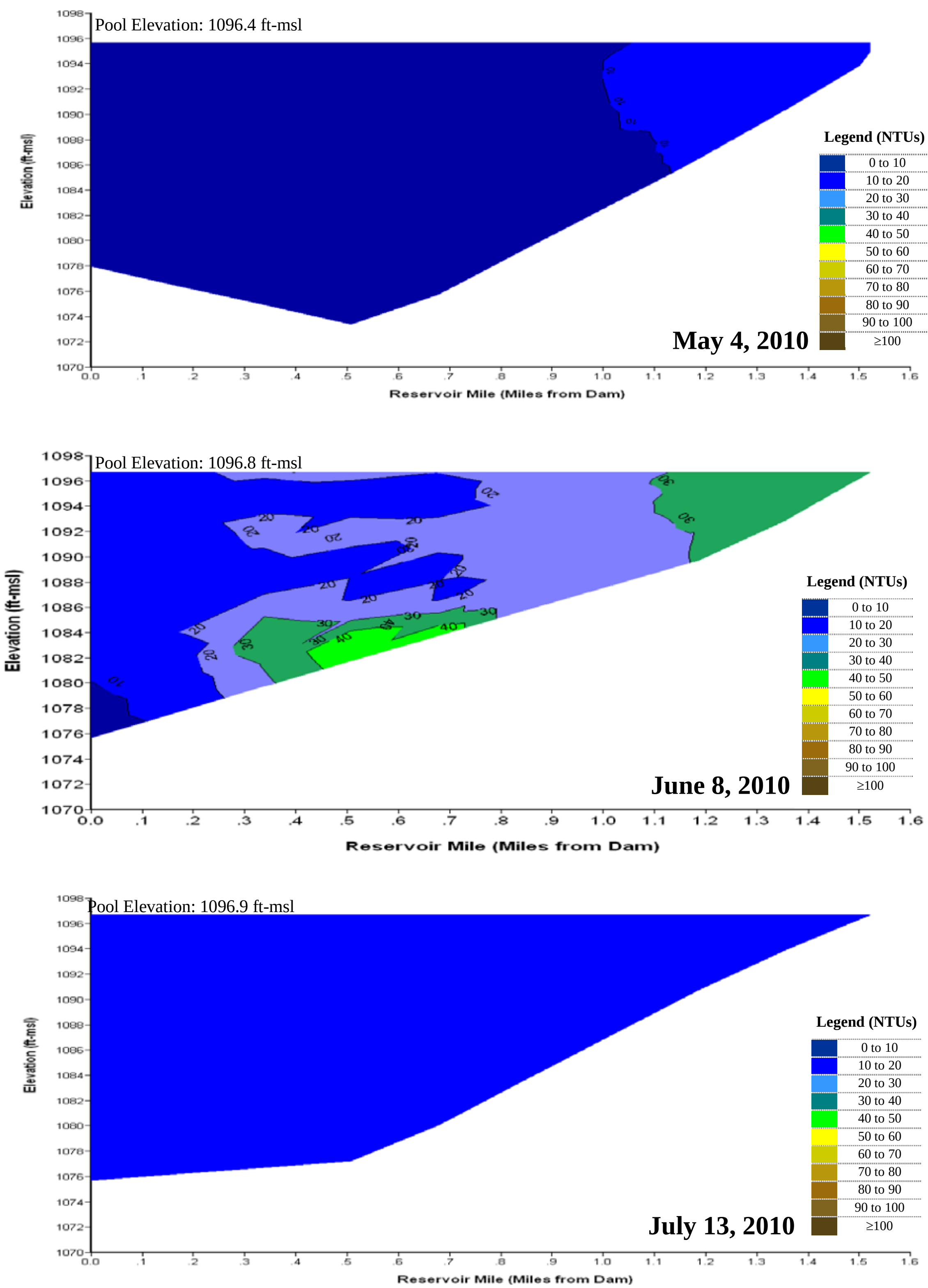
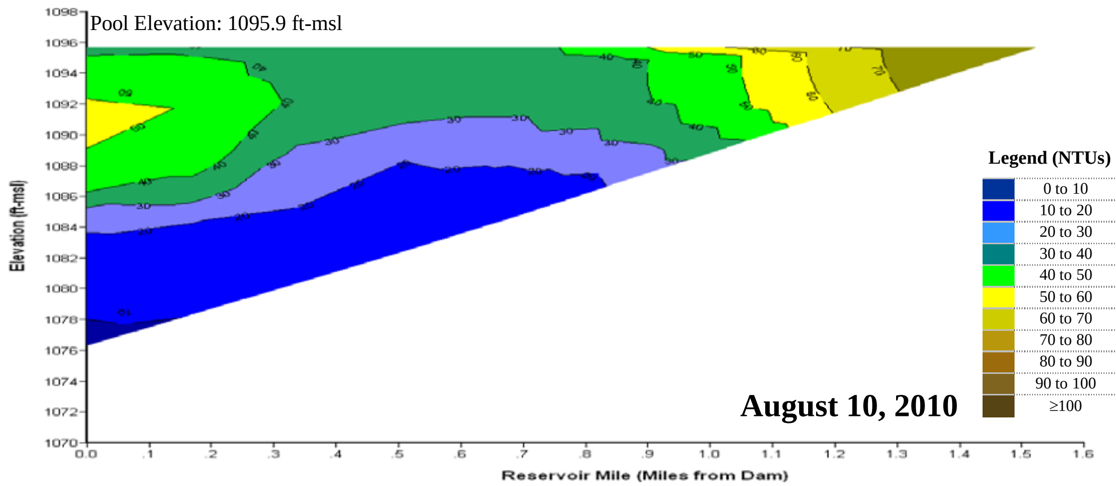


Plate 71. Longitudinal turbidity contour plots of Wehrspann Reservoir based on depth-profile turbidity levels (NTU) measured at sites WEHLKND1, WEHLKML1, and WEHLKUP1 in 2010.



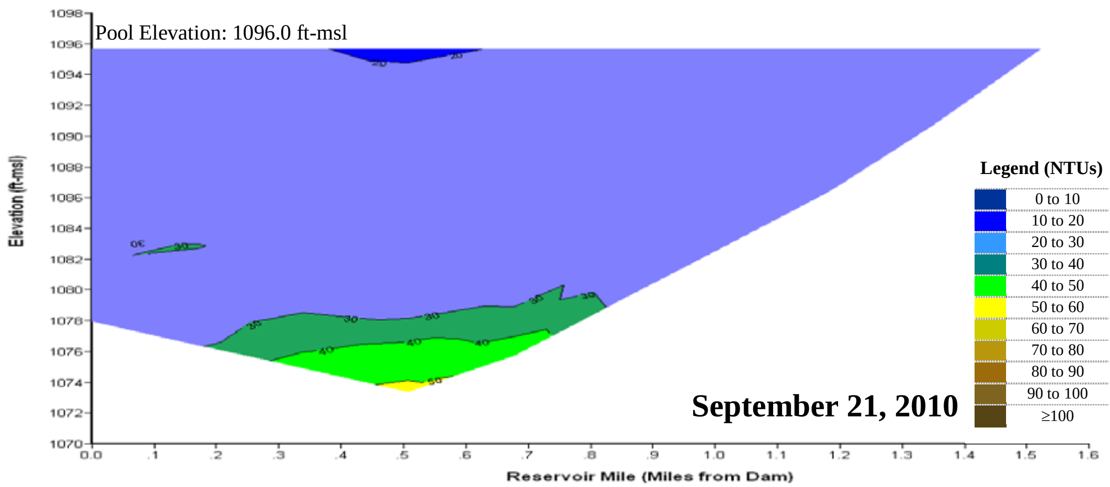


Plate 71. (Continued).

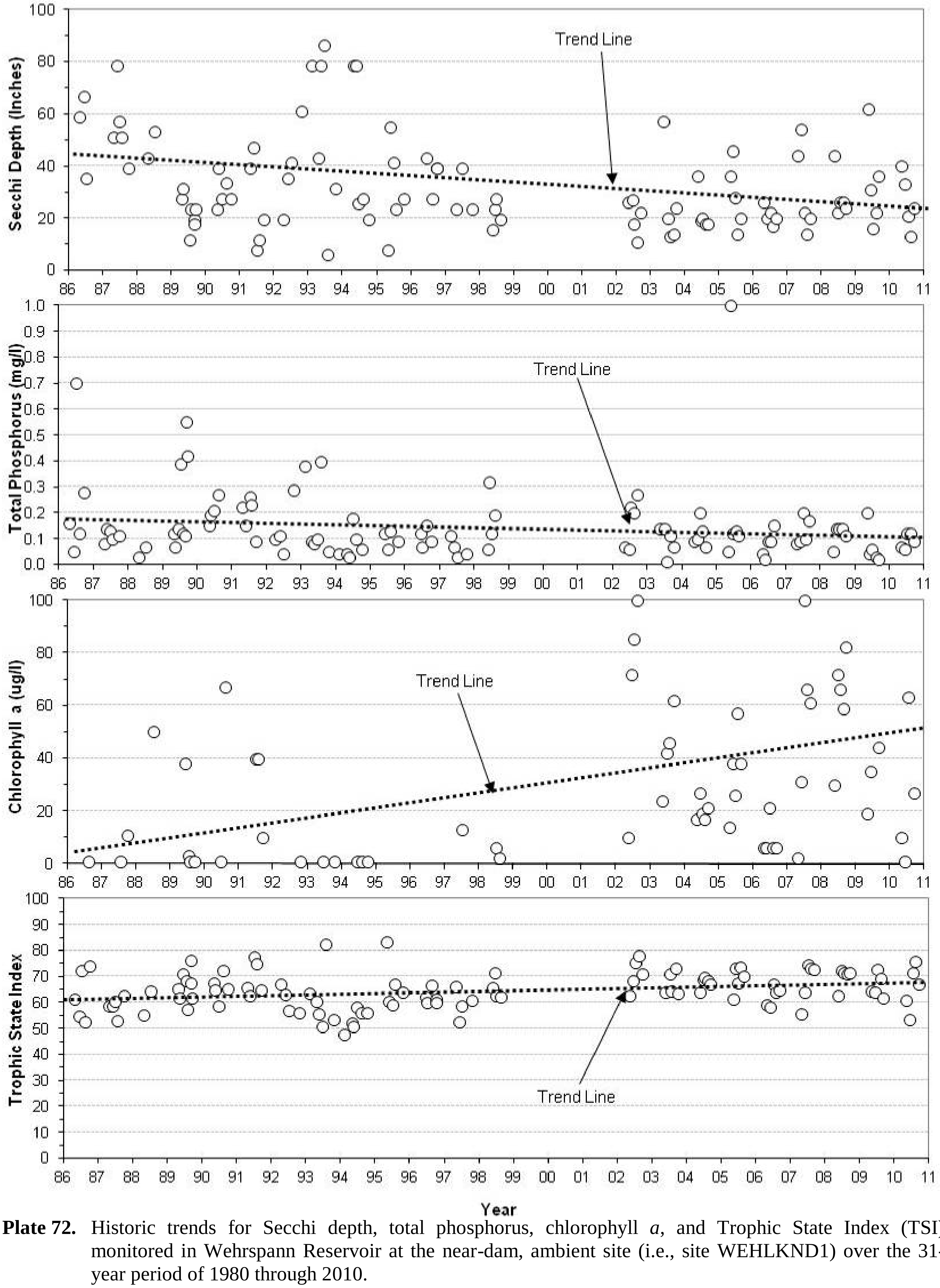


Plate 72. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Wehrspann Reservoir at the near-dam, ambient site (i.e., site WEHLKND1) over the 31-year period of 1980 through 2010.

Plate 73. Summary of runoff water quality conditions monitored in the main tributary inflow to Wehrspann Reservoir, upstream of the constructed sediment basin/wetland, at monitoring site WEHNFUSB1 during the period 2006 through 2010**.**

	Monitoring Results						Water Quality Standards Attainment		
Parameter	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Turbidity (NTUs)	1	13	1062	736	89	3555	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	15	0.20	0.21	n.d.	0.51	(1)	(1)	(1)
Kjeldahl N, Total (mg/l)	0.1	15	3.4	2.9	1.2	5.7	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	15	1.50	1.40	0.50	3.20	100(4)	0	0%
Phosphorus, Total (mg/l)	0.02	15	1.47	1.10	0.03	3.90	-----	-----	-----
Suspended Solids, Total (mg/l)	4	15	1199	1065	89	3700	-----	-----	-----
Acetochlor, Total (ug/l)[C]	0.05	3	-----	n.d.	n.d.	2.00	-----	-----	-----
Alachlor, Total (ug/l)[C]	0.05	7	-----	0.06	n.d.	0.10	760(2), 76(3)	0	0%
Atrazine, Total (ug/l)[C]	0.05	15	-----	0.49	n.d.	8.30	330(2), 12(3)	0	0%
Metolachlor, Total (ug/l)[C]	0.05	15	-----	0.10	n.d.	2.50	390(2), 100(3)	0	0%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Total ammonia criteria pH and temperature dependent. Since pH was not measured criteria are not calculated.
(2) Acute criterion for aquatic life.
(3) Chronic criterion for aquatic life.
(4) Agricultural criteria for surface waters.
(C) Immunoassay analysis.

Plate 74. Summary of runoff water quality conditions monitored in the main tributary inflow to Wehrspann Reservoir, immediately below the constructed sediment basin/wetland, at monitoring site WEHNFDSB1 during the period 2006 through 2010**.**

	Monitoring Results						Water Quality Standards Attainment		
Parameter	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Turbidity (NTUs)	1	13	139	38	6	687	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	15	0.26	0.23	n.d.	0.72	(1)	(1)	(1)
Kjeldahl N, Total (mg/l)	0.1	15	1.8	1.7	0.7	3.1	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	15	1.00	1.10	n.d.	2.70	100(4)	0	0%
Phosphorus, Total (mg/l)	0.02	15	0.47	0.44	0.04	1.30	-----	-----	-----
Suspended Solids, Total (mg/l)	4	15	155	45	10	630	-----	-----	-----
Acetochlor, Total (ug/l)[C]	0.05	8	-----	0.15	n.d.	1.80	-----	-----	-----
Alachlor, Total (ug/l)[C]	0.05	7	-----	n.d.	n.d.	0.30	760(2), 76(3)	0	0%
Atrazine, Total (ug/l)[C]	0.05	15	-----	0.71	n.d.	4.90	330(2), 12(3)	0	0%
Metolachlor, Total (ug/l)[C]	0.05	15	-----	n.d.	n.d.	2.50	390(2), 100(3)	0	0%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Total ammonia criteria pH and temperature dependent. Since pH was not measured criteria are not calculated.
(2) Acute criterion for aquatic life.
(3) Chronic criterion for aquatic life.
(C) Immunoassay analysis.

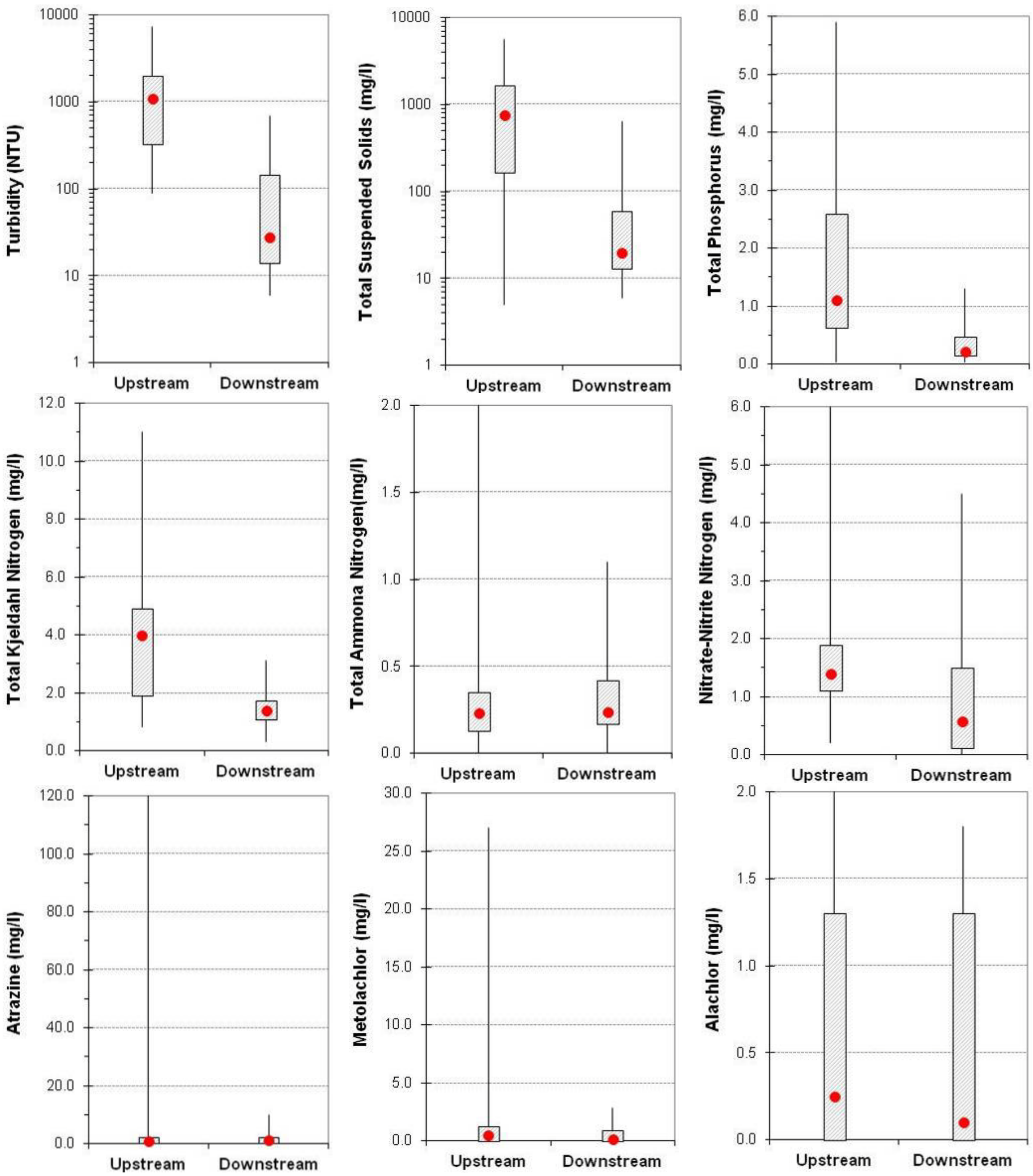


Plate 75. Box plots comparing paired runoff samples collected upstream (i.e., site WEHNFUSB1) and downstream (i.e., WEHNFDSB1) of the constructed sediment basin/wetland at Wehrspann Reservoir during the period 2002 through 2010. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

Plate 76. Summary of water quality conditions monitored in Bluestem Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site BLULKND1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for “grab samples” collected at a near-surface depth. Results for other parameters are for “grab samples” collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	25	1306.1	1306.5	1301.6	1308.9	-----	-----	-----
Water Temperature (°C)	0.1	202	23.0	23.5	15.8	28.9	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	202	6.8	6.9	0.3	9.5	≥ 5[2]	23	11%
Dissolved Oxygen (% Sat.)	0.1	196	81.6	85.3	4.2	122.3	-----	-----	-----
Specific Conductance (umho/cm)	1	196	317	312	136	392	2,000[3]	0	0%
pH (S.U.)	0.1	196	7.9	7.8	7.2	9.0	≥6.5 & ≤9.0[1]	0	0%
Turbidity (NTUs)	1	196	170	89	17	1082	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	196	339	341	206	525	-----	-----	-----
Secchi Depth (in.)	1	25	9	7	2	24	-----	-----	-----
Alkalinity, Total (mg/l)	7	50	120	120	77	149	20[1]	0	0%
Ammonia, Total (mg/l)	0.02	50	-----	0.04	n.d.	1.24	12.1 [4,5], 1.77 [4,6]	0	0%
Chlorophyll *a* (ug/l) – Field Probe	1	169	15	5	2	109	10[7]	53	31%
Chlorophyll *a* (ug/l) – Lab Determined	1	22	21	14	0	89	10[7]	12	55%
Hardness, Total (mg/l)	0.4	5	120.4	122.0	102.0	132.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	50	1.4	1.3	0.5	3.8	-----	-----	-----
Nitrogen, Total (mg/)	0.1	50	1.9	1.7	0.5	4.6	1 [7]	46	92%
Nitrate-Nitrite N, Total (mg/l)	0.02	50	0.50	0.50	0.00	1.40	100[3]	0	0%
Phosphorus, Total (mg/l)	0.02	50	0.29	0.23	0.09	0.78	0.05[7]	50	100%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	0.11	0.13	0.00	0.18	-----	-----	-----
Suspended Solids, Total (mg/l)	4	50	41	20	6	254	-----	-----	-----
Aluminum, Dissolved (ug/l)	25	5	-----	n.d.	n.d.	47	750[5], 87[6]	0	0%
Antimony, Dissolved (ug/l)	6	5	-----	1	n.d.	1	88[5], 30[6]	0	0%
Arsenic, Dissolved (ug/l)	3	5	6	5	5	10	340[5], 16.7[8]	0	0%
Beryllium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	130[5], 5.3[6]	0	0%
Cadmium, Dissolved (ug/l)	0.2	5	-----	n.d.	n.d.	n.d.	7.1[5], 0.28[6]	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	692[5], 90[6]	0	0%
Copper, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	2	16[5], 11 [6]	0	0%
Lead, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	79[5], 3.1[6]	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4[5]	0	0%
Mercury, Total (ug/l)	0.02	5	-----	n.d.	n.d.	0.03	0.77[6]	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	550[5], 61[6]	0	0%
Selenium, Total (ug/l)	2	5	-----	n.d.	n.d.	6	20[3,5], 5[6]	0, 1	0%, 20%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	4.8[5]	0	0%
Thallium (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	1,400[5], 6.3[8]	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	138[5,6]	0	0%
Microcystin, Total (ug/l)	0.05	25	-----	n.d.	n.d.	1.50	20[9]	0	0%
Acetochlor, Total (ug/l)[C]	0.05	15	0.81	0.60	n.d.	2.20	-----	-----	-----
Alachlor, Total (ug/l)[C]	0.05	10	0.22	0.20	n.d.	0.46	760[5], 76[6]	0	0%
Atrazine, Total (ug/l)[C]	0.05	25	1.69	1.00	0.20	8.30	330[5], 12[6]	0	0%
Metolachlor, Total (ug/l)[C]	0.05	25	-----	0.70	n.d.	2.90	390[5], 100[6]	0	0%
Pesticide Scan (ug/l)[D]	0.05						-----	-----	-----
Atrazine		5	-----	1.09	n.d.	9.30	330[5], 12[6]	0	0%
Deethylatrazine		4	-----	0.55	n.d.	1.20	-----	-----	-----
Deisopropylatrazine		4	-----	n.d.	n.d.	0.30	-----	-----	-----
Metolachlor		5	-----	n.d.	n.d.	1.70	390[5], 100[6]	0	0%

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l microcystins in recreation water for impairment assessment.
Note: Many of Nebraska’s WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Immunoassay analysis.

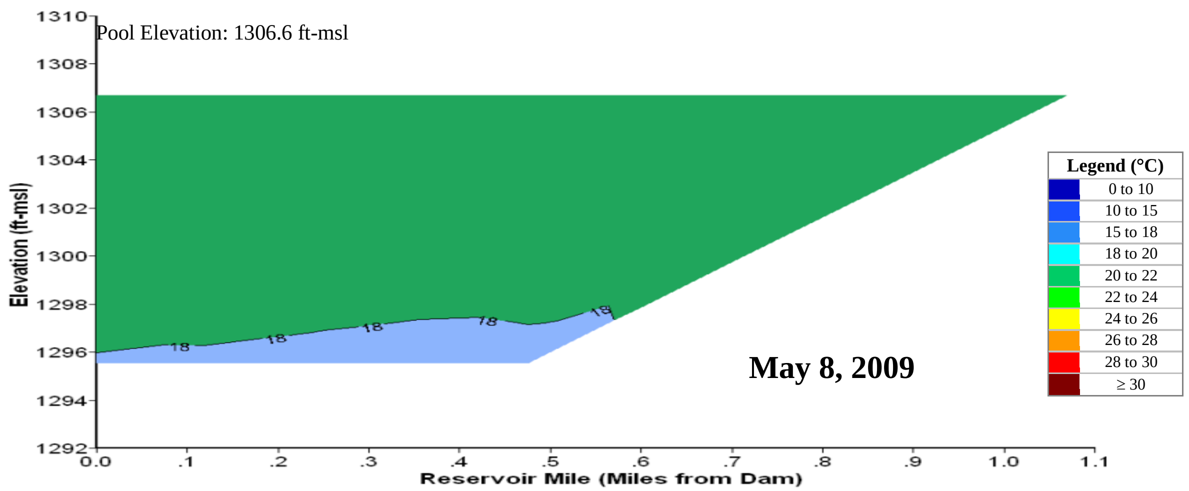
(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

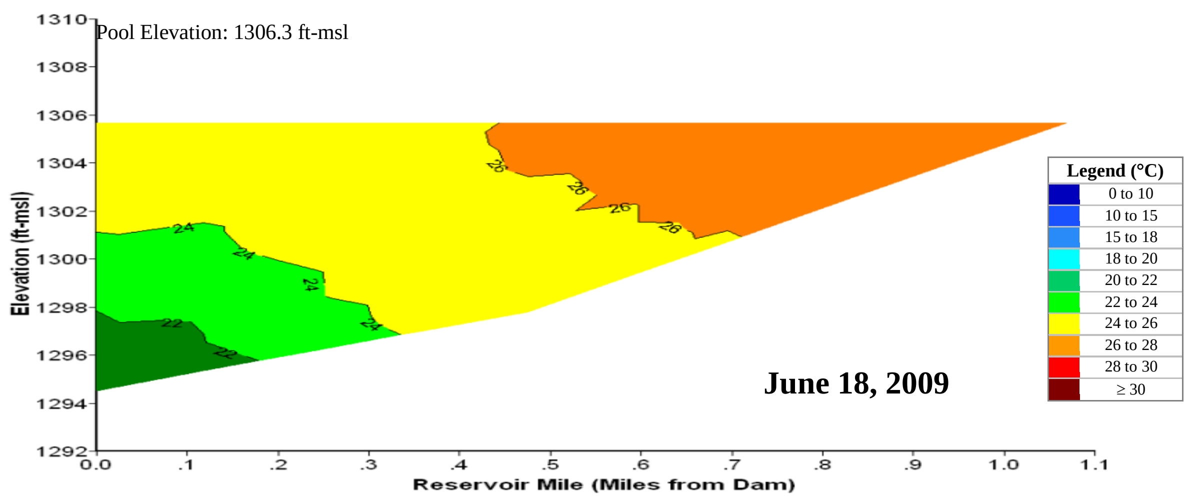
* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 77. Summary of water quality conditions monitored in Bluestem Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site BLULKML1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	24	1306.1	1306.6	1301.6	1308.9	-----	-----	-----
Water Temperature (°C)	0.1	158	23.4	24.2	15.8	29.1	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	158	7.3	7.2	3.3	9.4	≥ 5[2]	4	3%
Dissolved Oxygen (% Sat.)	0.1	153	88.6	86.8	38.3	124.6	-----	-----	-----
Specific Conductance (umho/cm)	1	153	318	311	182	391	2,000[3]	0	0%
pH (S.U.)	0.1	153	8.0	7.9	7.2	9.0	≥6.5 & ≤9.0[1]	0	0%
Turbidity (NTUs)	1	153	152	93	18	712	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	153	345	343	238	513	-----	-----	-----
Secchi Depth (in.)	1	25	10	6	2	36	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	131	13	5	1	44	16[4]	40	31%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).
(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.





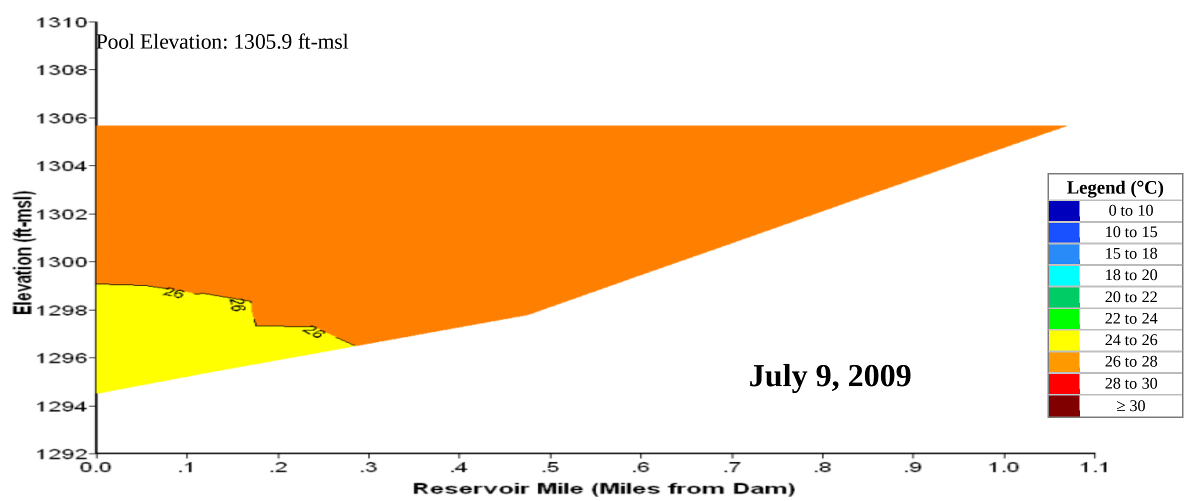
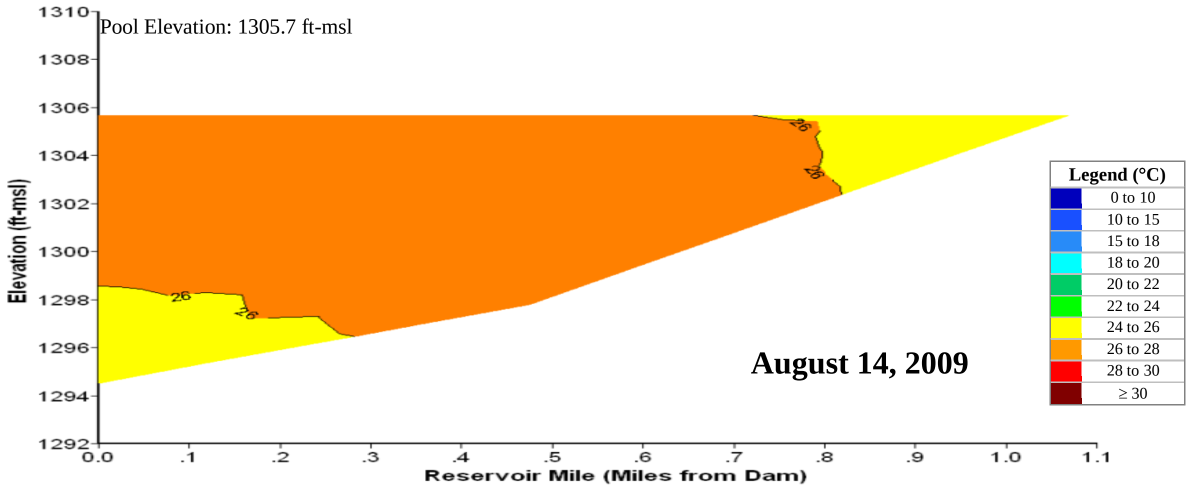


Plate 78. Longitudinal water temperature (°C) contour plots of Bluestem Reservoir based on depth-profile water temperatures measured at sites BLULKND1 and BLULKML1 in 2009.



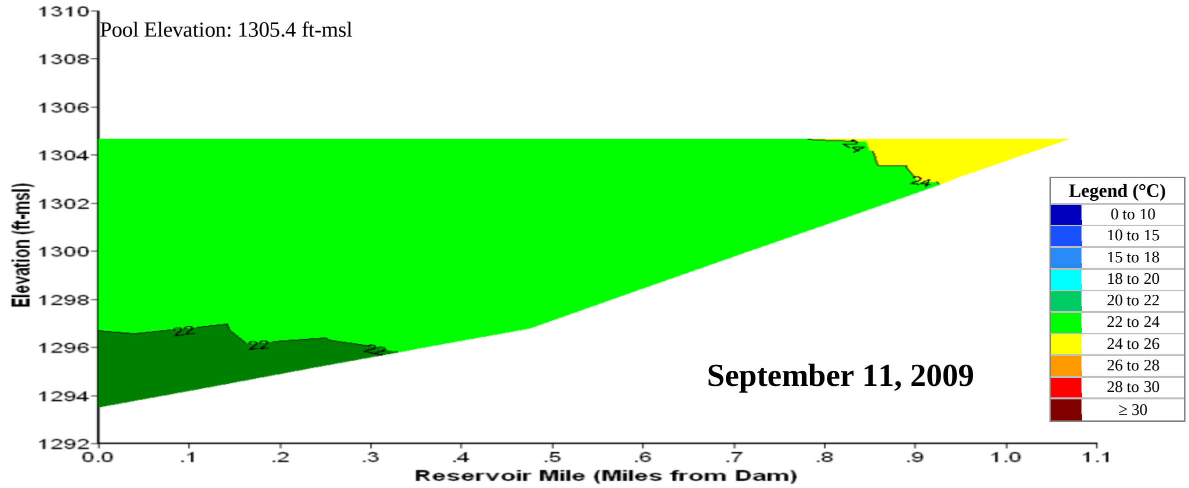
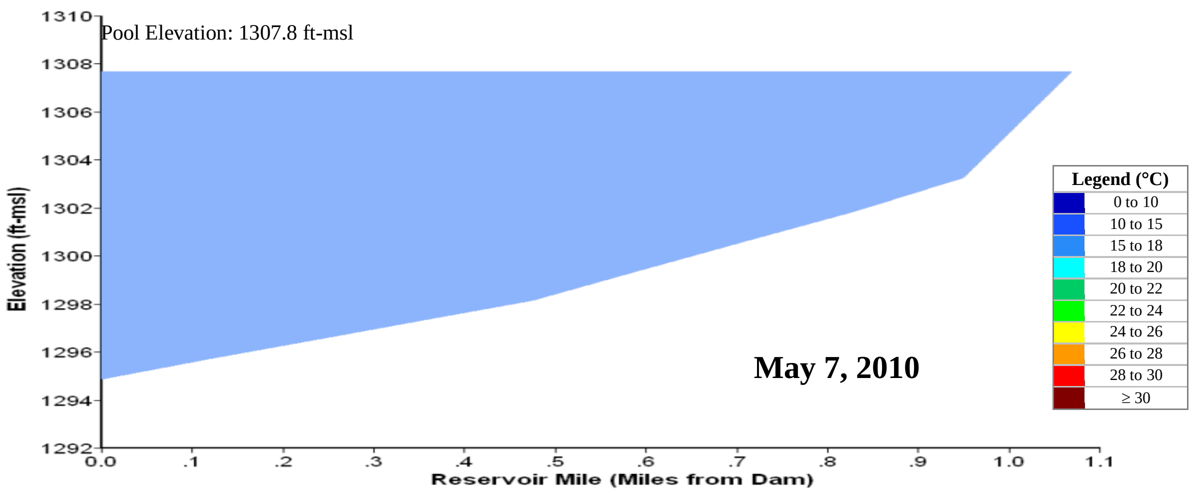
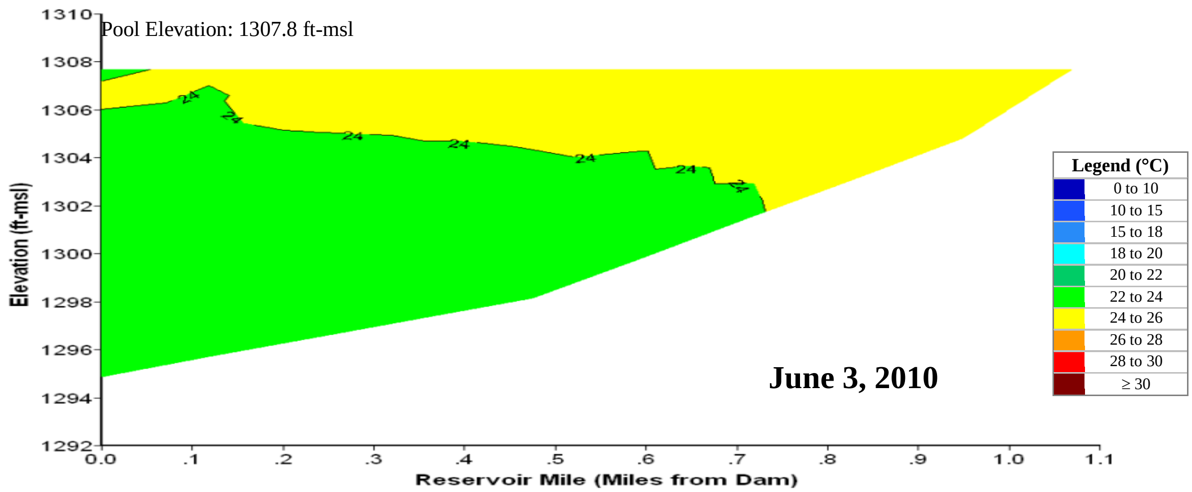


Plate 78. (Continued).





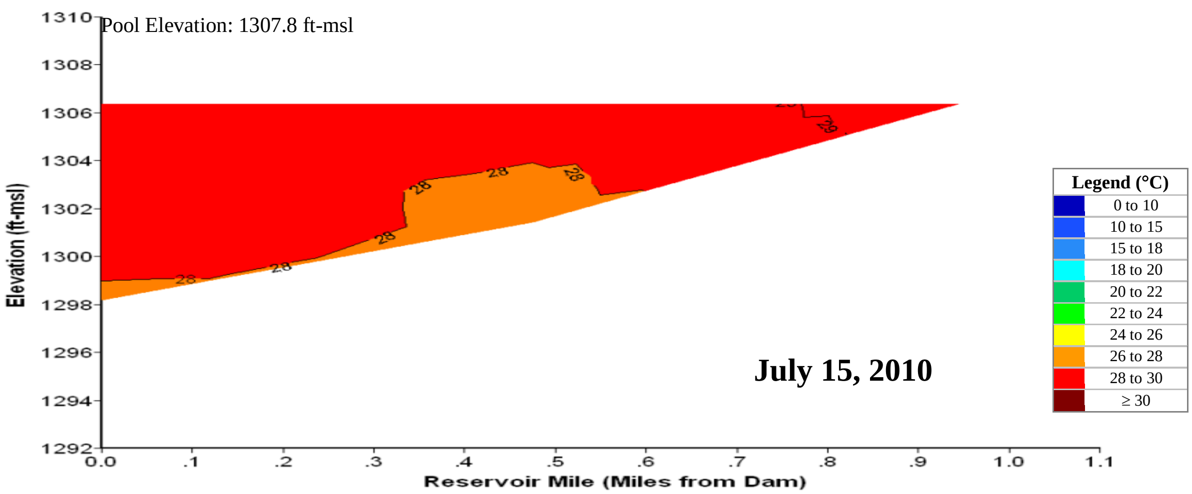
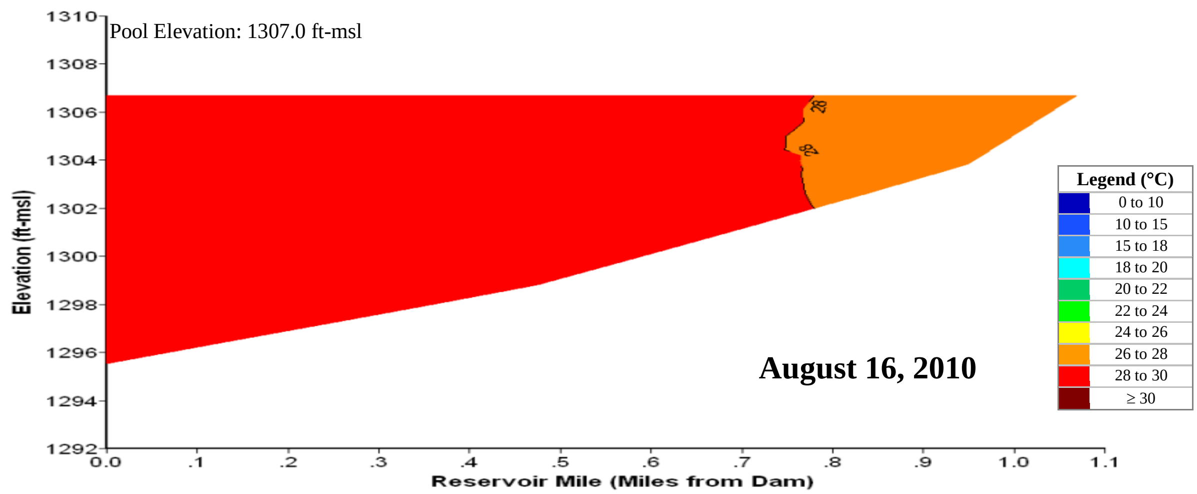


Plate 79. Longitudinal water temperature (°C) contour plots of Bluestem Reservoir based on depth-profile water temperatures measured at sites BLULKND1, BLULKML1, and BLULKUP1 in 2010.



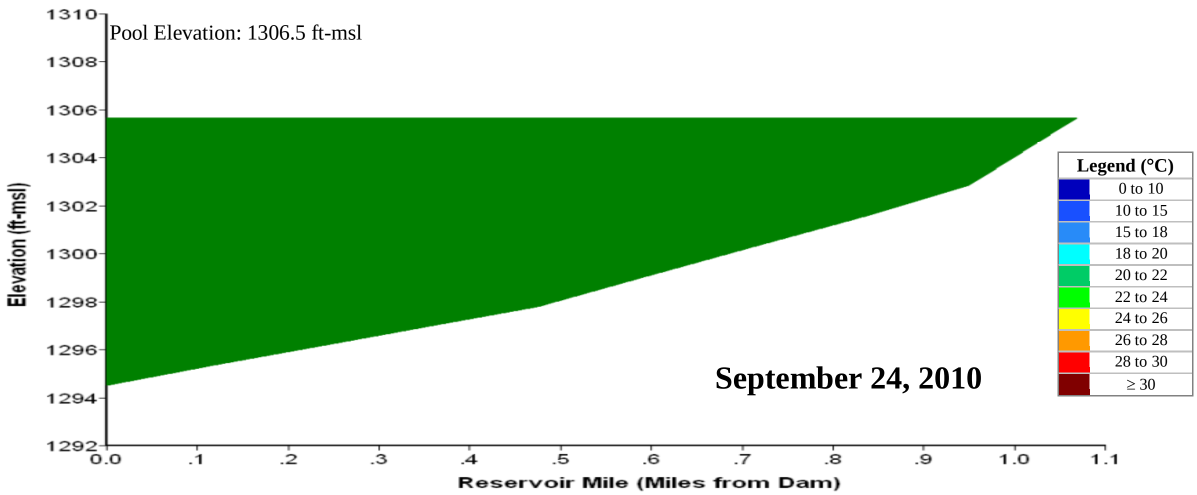


Plate 79. (Continued).

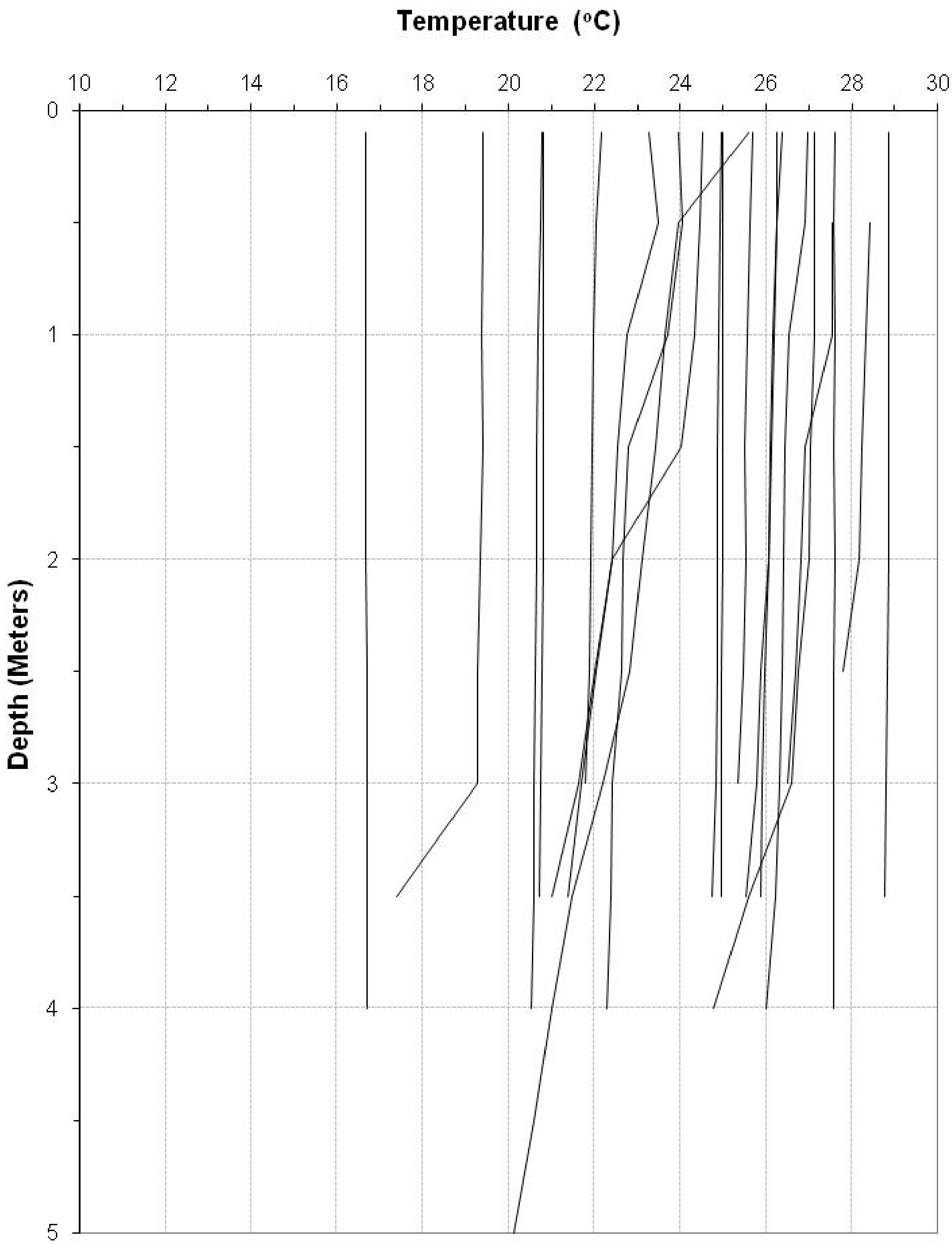
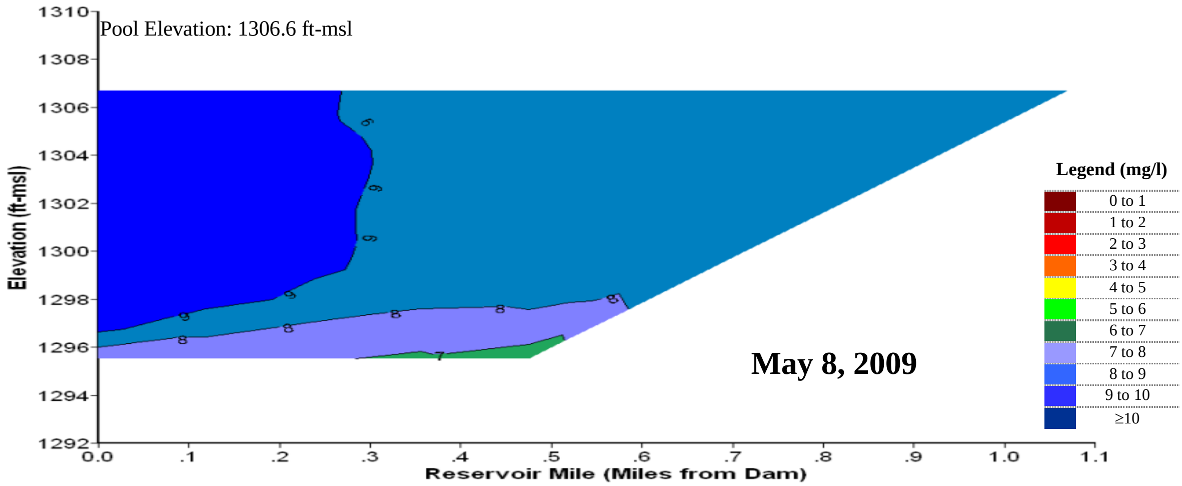
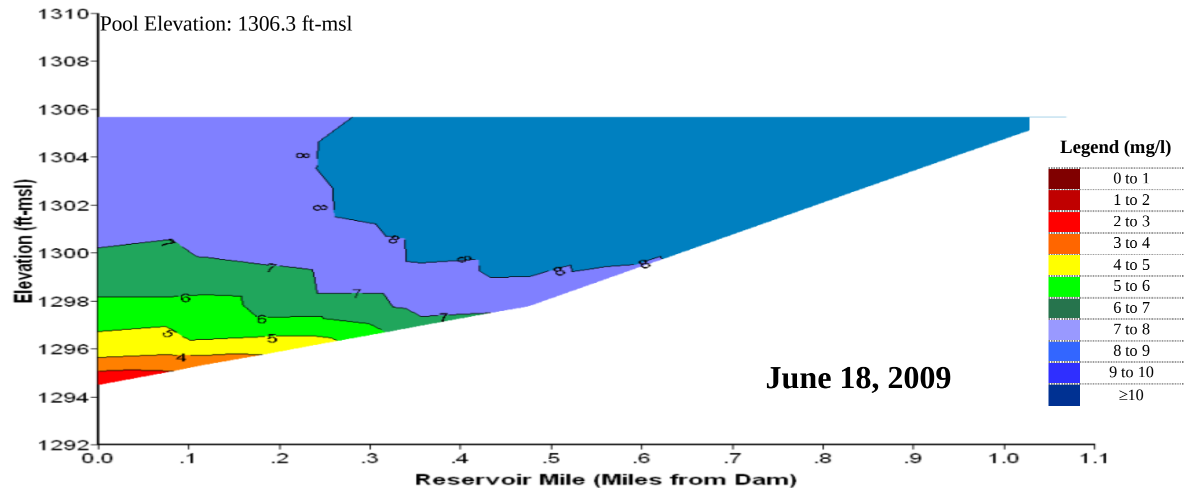


Plate 80. Temperature depth profiles for Bluestem Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., BLULKND1) during the summer over the 5-year period of 2006 to 2010.





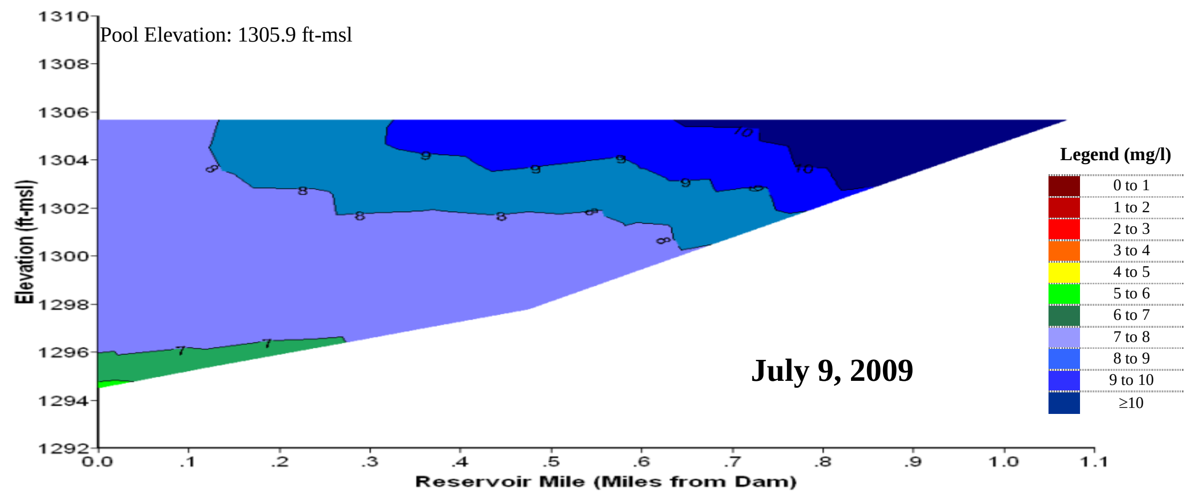
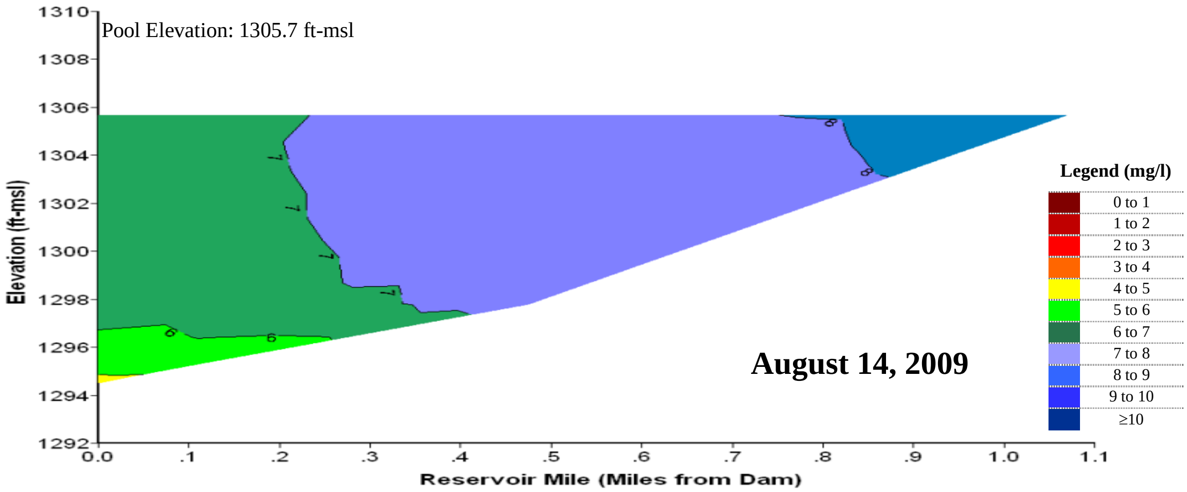


Plate 81. Longitudinal dissolved oxygen (mg/l) contour plots of Bluestem Reservoir based on depth-profile dissolved oxygen concentrations measured at sites BLULKND1 and BLULKML1 in 2009.



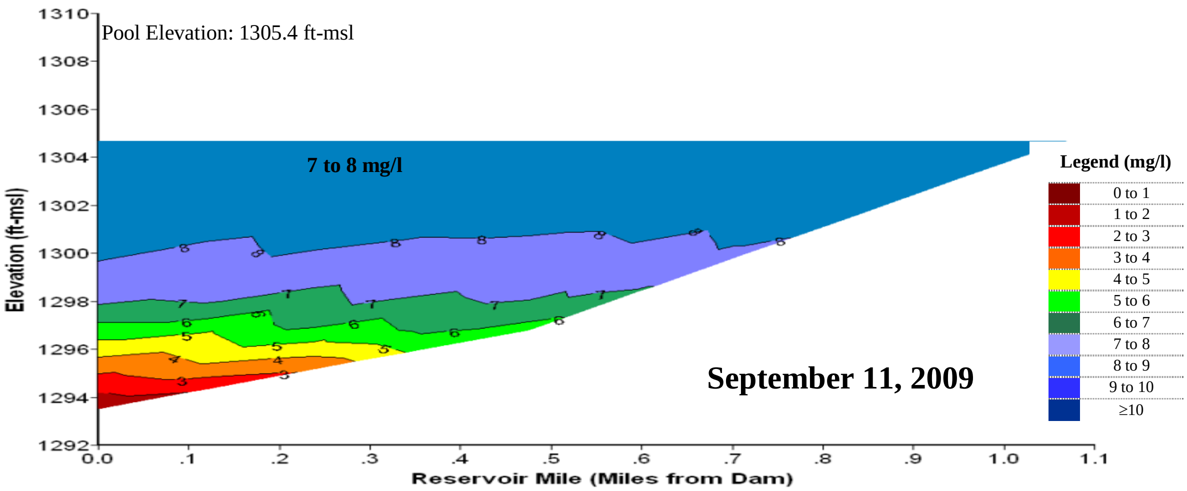


Plate 81. (Continued).

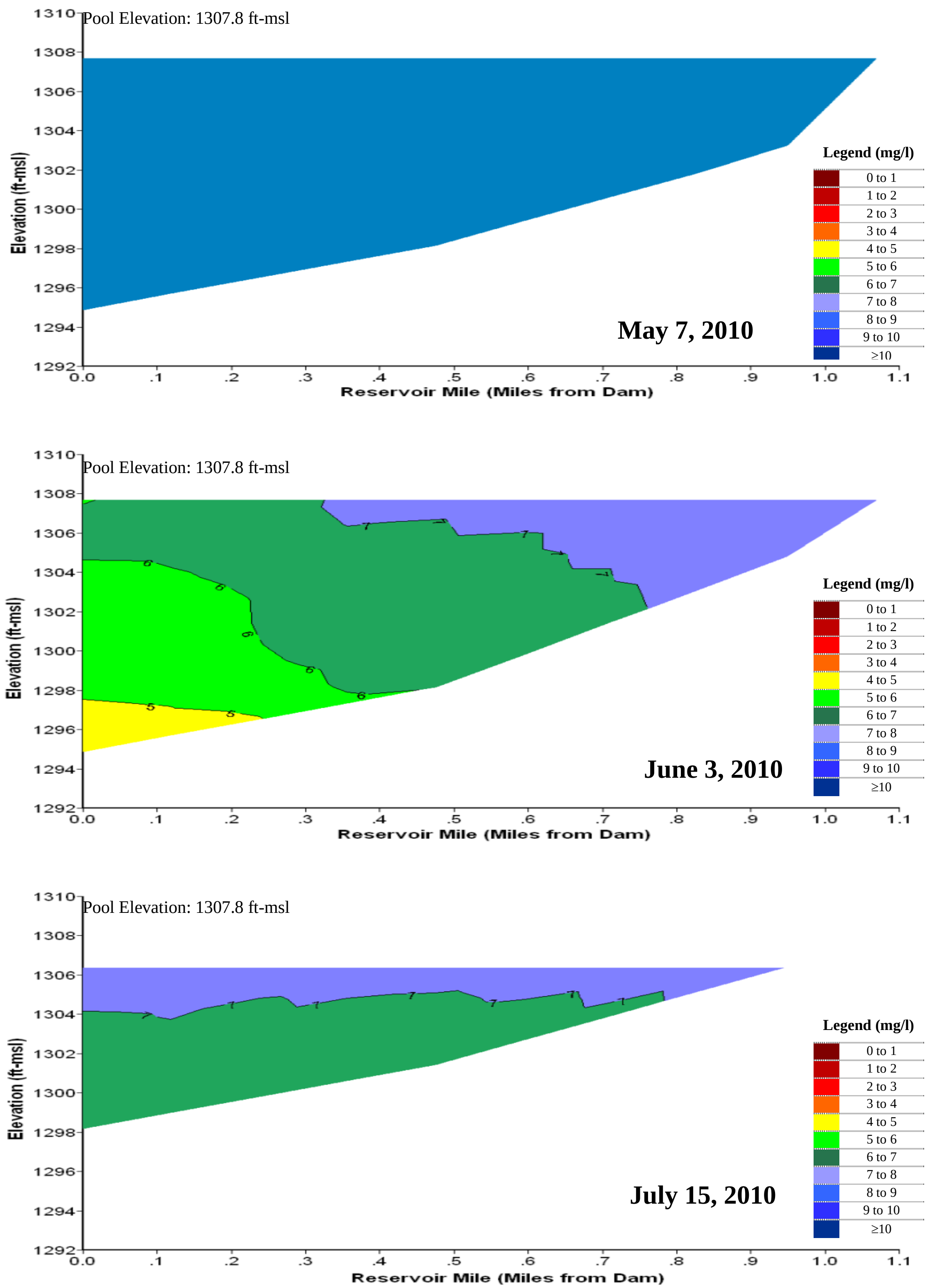
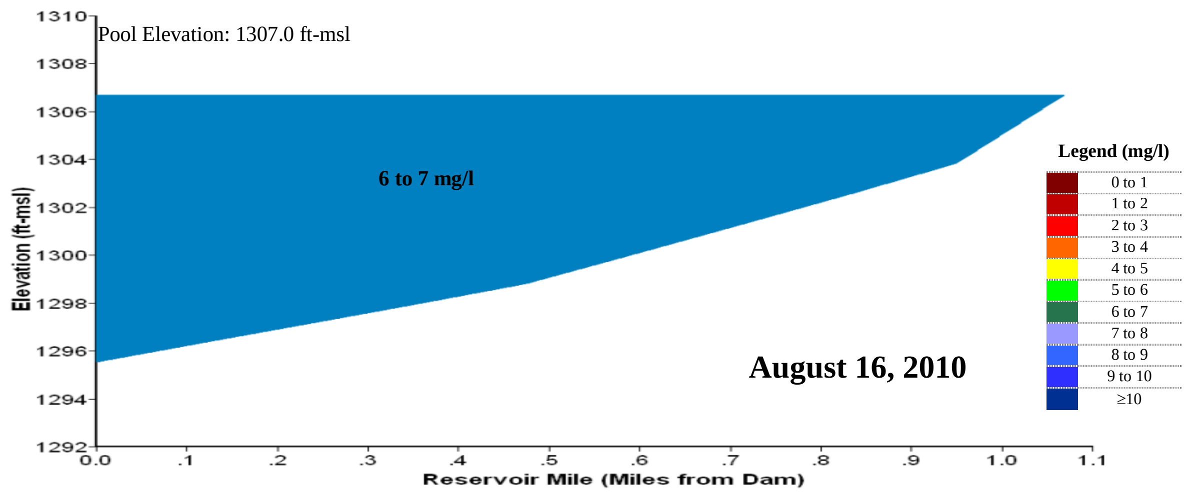


Plate 82. Longitudinal dissolved oxygen (mg/l) contour plots of Bluestem Reservoir based on depth-profile dissolved oxygen concentrations measured at sites BLULKND1, BULKML1, and BLULKUP1 in 2010.



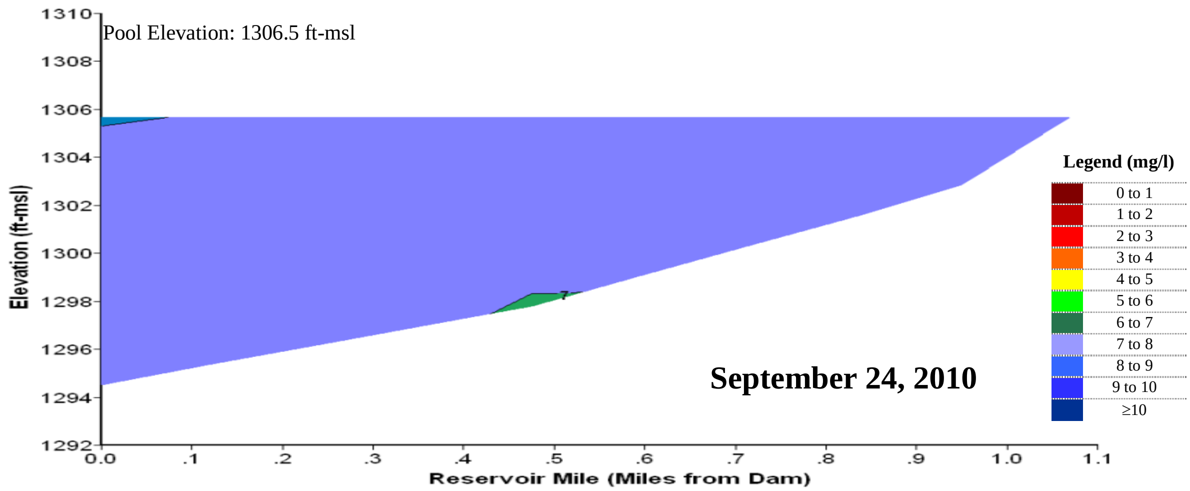


Plate 82. (Continued).

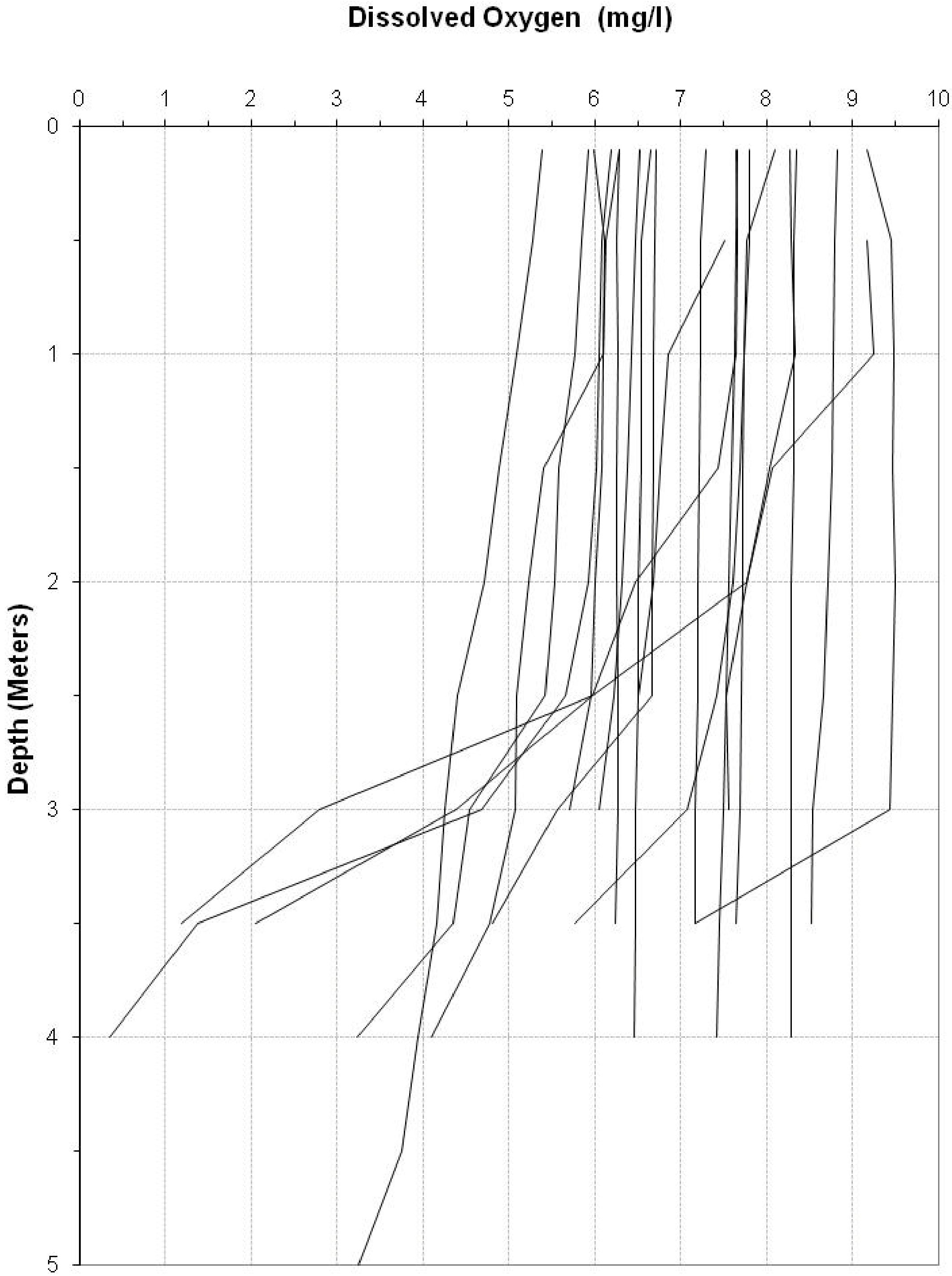


Plate 83. Dissolved oxygen depth profiles for Bluestem Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., BLULKND1) during the summer over the 5-year period of 2006 through 2010.

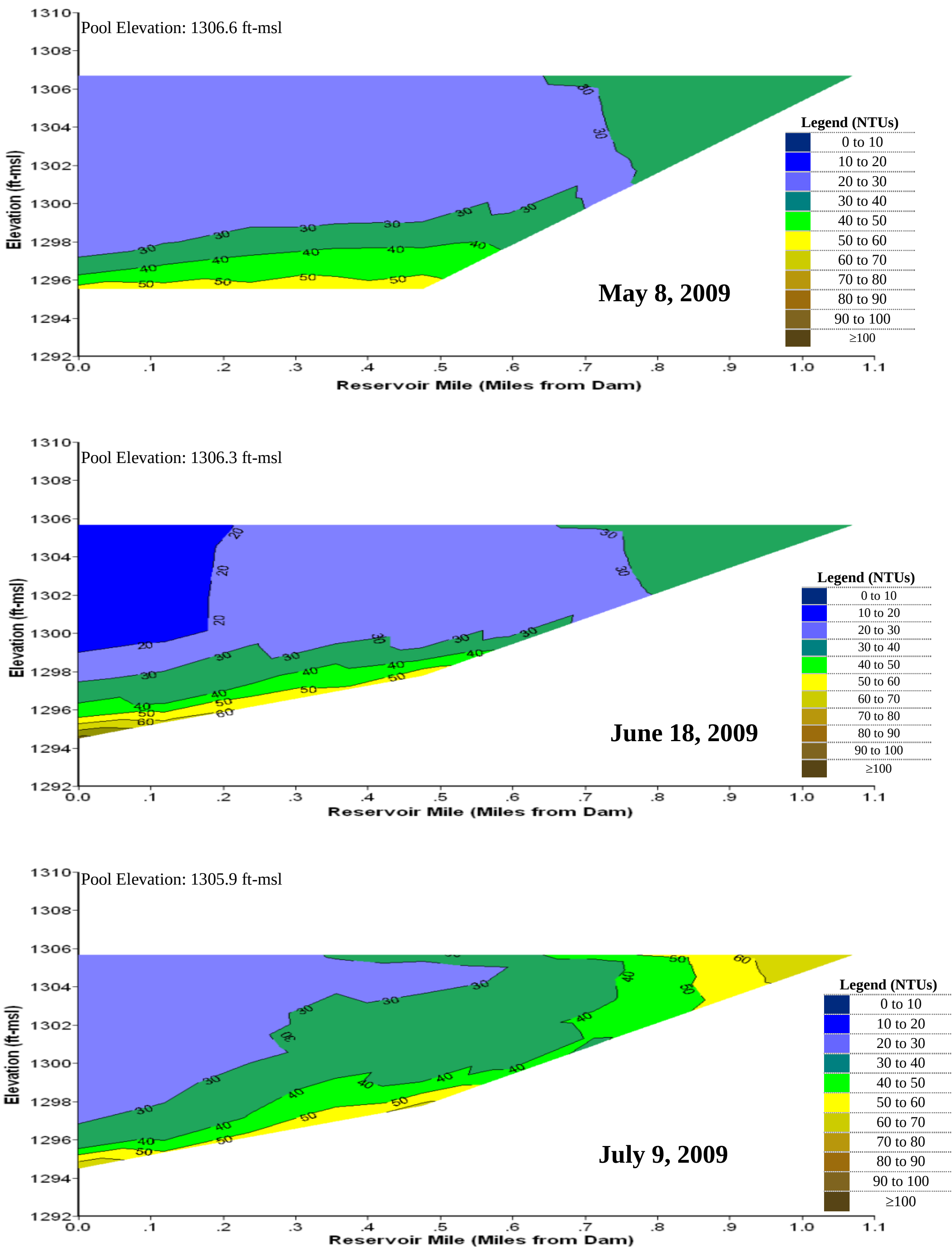
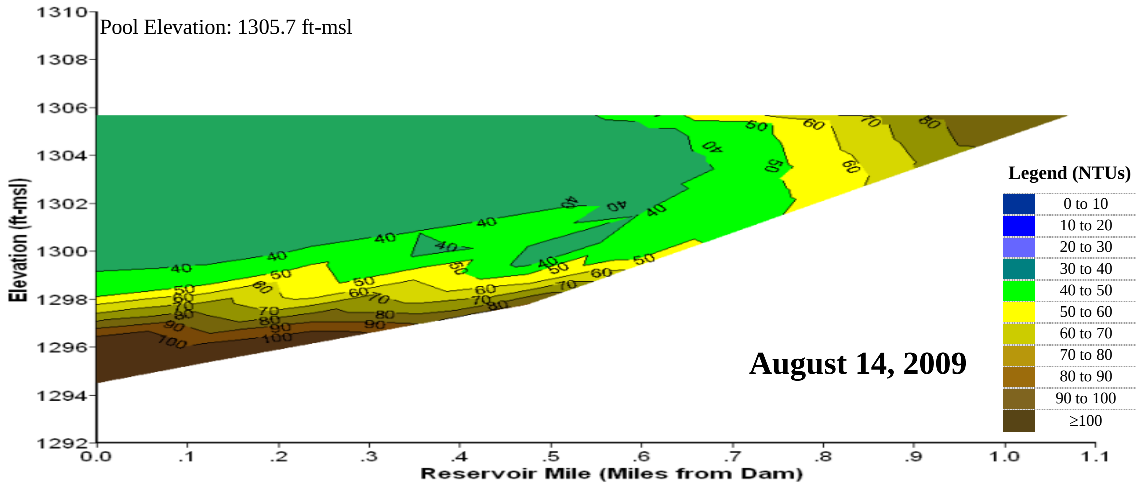


Plate 84. Longitudinal turbidity (NTU) contour plots of Bluestem Reservoir based on depth-profile turbidity levels measured at sites BLULKND1 and BLULKML1 in 2009.



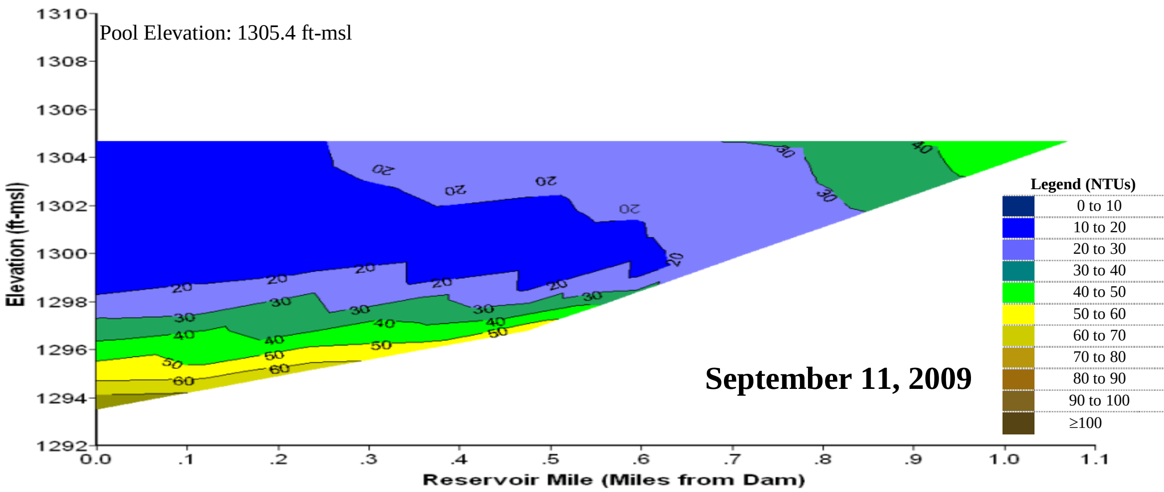


Plate 84. (Continued).

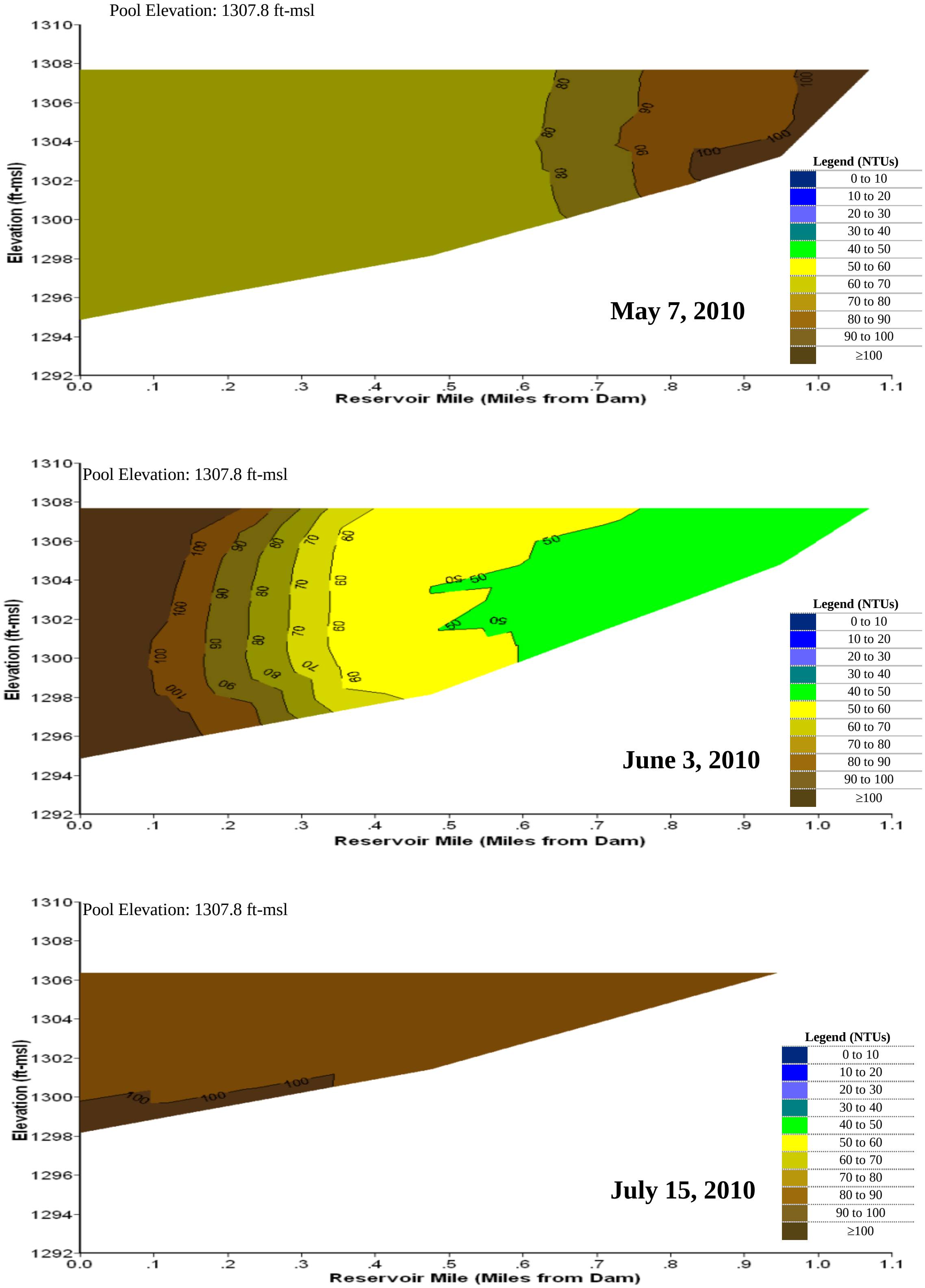
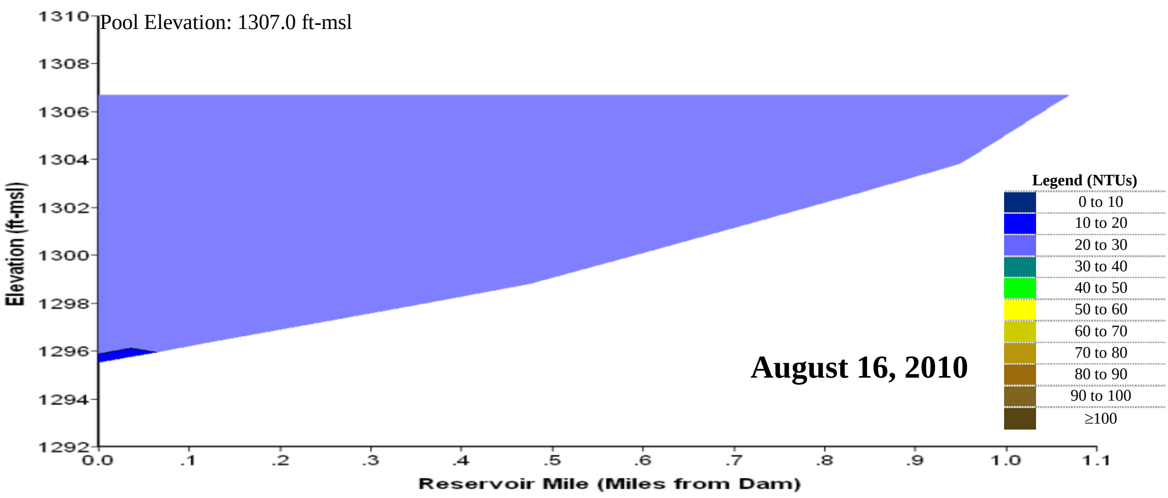


Plate 85. Longitudinal turbidity (NTU) contour plots of Bluestem Reservoir based on depth-profile turbidity levels measured at sites BLULKND1, BLULKML1, and BLULKUP1 in 2010.



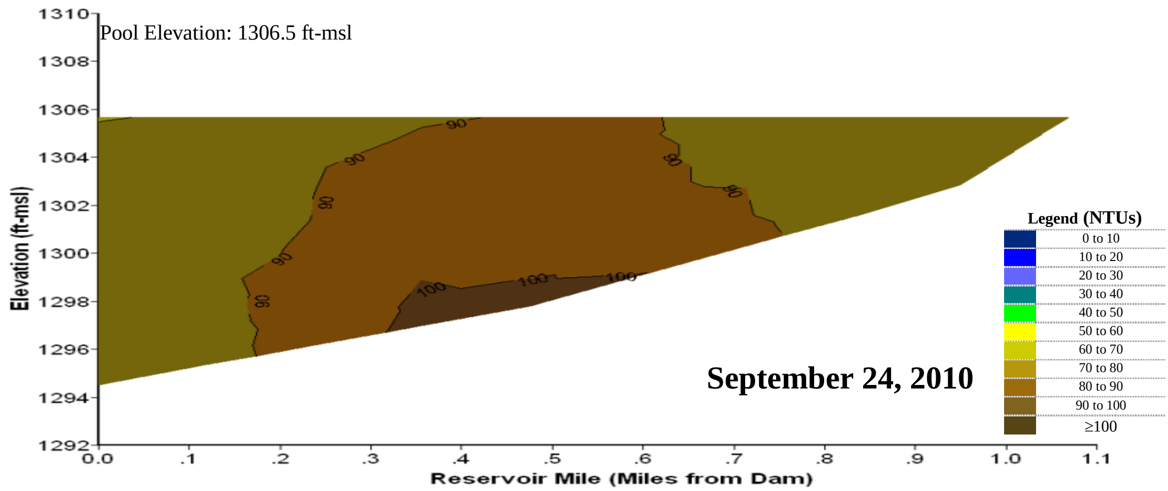


Plate 85. (Continued).

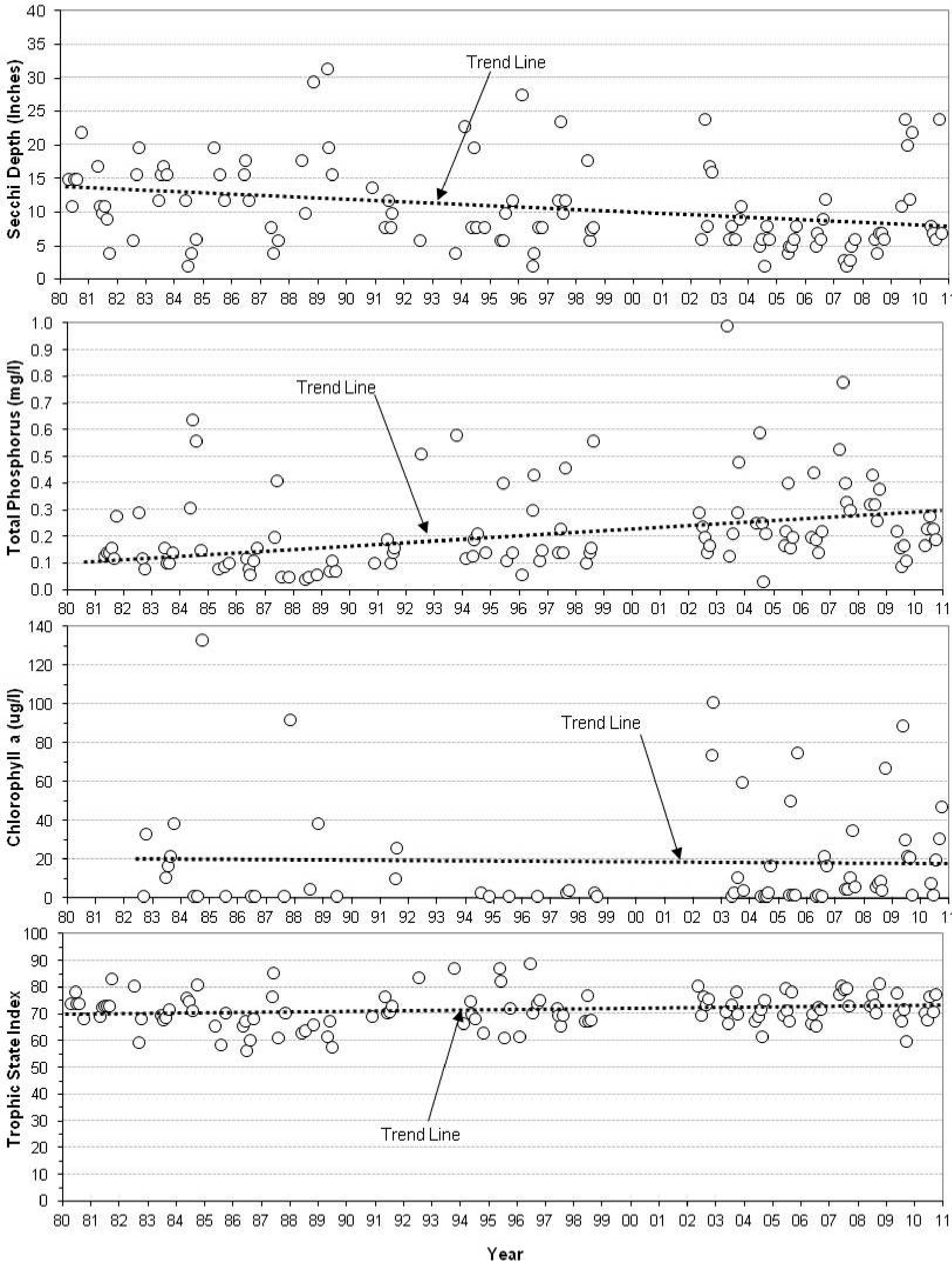


Plate 86. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Bluestem Reservoir at the near-dam, ambient site (i.e., site BLULKND1) over the 31-year period of 1980 through 2010.

Plate 87. Summary of runoff water quality conditions monitored in the main north tributary inflow to Bluestem Reservoir at monitoring site BLUNFNRT1 during the 5-year period 2004 through 2008**.** Runoff conditions have not been monitored since 2008.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Kjeldahl N, Total (mg/l)	0.1	9	4.4	4.2	1.6	7.6	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	9	4.44	1.68	0.95	26.75	100(3)	0	0%
Phosphorus, Total (mg/l)	0.02	9	1.58	1.35	0.66	3.01	-----	-----	-----
Suspended Solids, Total (mg/l)	4	9	1,009	452	90	5,600	-----	-----	-----
Acetochlor, Total (ug/l)(C)	0.05	7	4.62	2.48	0.24	13.50	-----	-----	-----
Alachlor, Total (ug/l)(C)	0.05	2	0.20	0.20	0.14	0.25	760(1), 76(2)	0	0%
Atrazine, Total (ug/l)(C)	0.05	9	18.35	4.03	1.43	105.04	330(1), 12(2)	0, 3	0%, 33%
Metolachlor, Total (ug/l)(C)	0.05	9	2.16	1.46	n.d.	6.20	390(1), 100(2)	0	0%
E. Coli (cfu/100ml)	1	10	18,522	22,028	2,500	25,000	-----	-----	-----

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Acute criterion for aquatic life.
(2) Chronic criterion for aquatic life.
(3) Agricultural criteria for surface waters.
(C) Immunoassay analysis.

Plate 88. Summary of runoff water quality conditions monitored in the main west tributary inflow to Bluestem Reservoir at monitoring site BLUNFWST1 during the 5-year period 2004 through 2008**.** Runoff conditions have not been monitored since 2008.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Kjeldahl N, Total (mg/l)	0.1	9	4.4	3.5	1.9	7.2	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	9	2.51	0.95	0.40	9.84	100(3)	0	0%
Phosphorus, Total (mg/l)	0.02	9	1.33	1.40	0.71	2.20	-----	-----	-----
Suspended Solids, Total (mg/l)	4	9	1,367	1,200	188	3,860	-----	-----	-----
Acetochlor, Total (ug/l)(C)	0.05	7	3.27	0.99	0.39	11.50	-----	-----	-----
Alachlor, Total (ug/l)(C)	0.05	2	0.38	0.38	0.27	3.50	760(1), 76(2)	0	0%
Atrazine, Total (ug/l)(C)	0.05	9	24.18	4.07	1.41	165.30	330(1), 12(2)	0, 3	0%, 33%
Metolachlor, Total (ug/l)(C)	0.05	8	1.38	1.63	n.d.	3.50	390(1), 100(2)		
E. Coli (cfu/100ml)	1	10	13,651	8,455	2,500	25,000	-----	-----	-----

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Acute criterion for aquatic life.
(2) Chronic criterion for aquatic life.
(3) Agricultural criteria for surface waters.
(C) Immunoassay analysis.

Plate 89. Summary of water quality conditions monitored in Branched Oak Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site BOKLKND1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	25.0	1283.4	1284.3	1278.9	1285.4	-----	-----	-----
Water Temperature (°C)	0.1	408.0	22.6	22.3	14.9	30.1	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	408.0	6.6	7.0	0.1	10.5	≥ 5(2)	65	16%
Dissolved Oxygen (% Sat.)	0.1	394.0	77.5	86.9	1.8	136.1	-----	-----	-----
Specific Conductance (umho/cm)	1	394	432	431	1	498	2,000(3)	0	0%
pH (S.U.)	0.1	394.0	8.2	8.2	7.1	8.8	≥6.5 & ≤9.0(1)	0	0%
Turbidity (NTUs)	1	394	16	12	3	295	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	394	333	339	-67	508	-----	-----	-----
Secchi Depth (in.)	1	25	30	29	19	46	-----	-----	-----
Alkalinity, Total (mg/l)	7	50	179	175	150	217	20(1)	0	0%
Ammonia, Total (mg/l)	0.01	50	-----	0.12	0.00	1.13	5.72 (4,5), 1.09 (4,6)	0, 1	0%, 2%
Chlorophyll *a* (ug/l) – Field Probe	1	334	27.64	17.07	0.73	88.15	10(7)	245	73%
Chlorophyll *a* (ug/l) – Lab Determined	1	25	30.90	36.00	0.00	92.00	10(7)	18	72%
Hardness, Total (mg/l)	0.4	5	165	168	156	177	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.10	50	1.2	1.1	0.0	2.1	-----	-----	-----
Nitrogen, Total (mg/)	0.10	50	1.2	1.1	0.0	2.1	1(7)	34	68%
Nitrate-Nitrite N, Total (mg/l)	0.02	50	-----	n.d.	0.00	0.09	100(3)	0	0%
Phosphorus, Total (mg/l)	0.10	50	0.1	0.1	0.0	0.3	0.05(7)	41	82%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	-----	0.02	0.00	0.23	-----	-----	-----
Suspended Solids, Total (mg/l)	4	50	-----	11	n.d.	33	-----	-----	-----
Aluminum, Dissolved (ug/l)	25	5	-----	n.d.	n.d.	33	750(5), 87(6)	0	0%
Antimony, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	1	88(5), 30(6)	0	0%
Arsenic, Dissolved (ug/l)	3	5	-----	n.d.	n.d.	7	340(5), 16.7(8)	0	0%
Beryllium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	130(5), 5.3(6)	0	0%
Cadmium, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	9.8(5), 0.4(6)	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	2	905(5), 118(6)	0	0%
Copper, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	22(5), 14(6)	0	0%
Lead, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	113(5), 4(6)	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4(5)	0	0%
Mercury, Total (ug/l)	0.08	5	-----	n.d.	n.d.	n.d.	0.77(6)	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	726(5), 80(6)	0	0%
Selenium, Total (ug/l)	2	4	-----	n.d.	n.d.	n.d.	20(3,5), 5(6)	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	8.4(5)	0	0%
Thallium (ug/l)	3	5	-----	n.d.	n.d.	n.d.	1,400(5), 6.3(8)	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	182(5,6)	0	0%
Microcystin, Total (ug/l)	0.05	24	-----	n.d.	n.d.	0.60	20(9)	0	0%
Acetochlor, Total (ug/l)(C)	0.05	15	-----	0.20	n.d.	0.70	-----	-----	-----
Alachlor, Total (ug/l)(C)	0.05	9	-----	0.09	n.d.	0.27	760(5), 76(6)	0	0%
Atrazine, Total (ug/l)(C)	0.05	24	1.52	1.30	0.50	2.80	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l)(C)	0.05	24	-----	n.d.	n.d.	0.50	390(5), 100(6)	0	0%
Pesticide Scan (ug/l)(D)	0.05						-----	-----	-----
Atrazine		5	1.02	0.90	n.d.	2.80	330(5), 12(6)	0	0%
Deethylatrazine		4	0.08	n.d.	n.d.	0.30	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l microcystins in recreation water for impairment assessment.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 90. Summary of water quality conditions monitored in Branched Oak Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site BOKLKMLN1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	24	1283.4	1284.3	1278.9	1285.4	-----	-----	-----
Water Temperature (°C)	0.1	273	22.9	23.2	14.8	29.9	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	273	7.4	7.6	0.3	10.1	≥ 5(2)	22	8%
Dissolved Oxygen (% Sat.)	0.1	263	88.7	92.2	3.7	132.3	-----	-----	-----
Specific Conductance (umho/cm)	1	263	430	427	382	497	2,000(3)	0	0%
pH (S.U.)	0.1	263	8.3	8.3	7.5	8.9	≥6.5 & ≤9.0(1)	0	0%
Turbidity (NTUs)	1	263	18	14	4	432	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	263	344	349	116	528	-----	-----	-----
Secchi Depth (in.)	1	25	27	26	17	50	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	231	30	19	1	90	10(4)	200	87%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).
(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 91. Summary of water quality conditions monitored in Branched Oak Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site BOKLKMLS1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	24	1283.4	1284.3	1278.9	1285.4	-----	-----	-----
Water Temperature (°C)	0.1	254	22.8	23.3	14.8	29.5	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	254	7.1	7.3	0.8	11.2	≥ 5(2)	17	7%
Dissolved Oxygen (% Sat.)	0.1	248	84.8	85.4	10.1	132.5	-----	-----	-----
Specific Conductance (umho/cm)	1	248	432	428	382	505	2,000(3)	0	0%
pH (S.U.)	0.1	248	8.2	8.2	7.5	8.8	≥6.5 & ≤9.0(1)	0	0%
Turbidity (NTUs)	1	248	18	14	4	125	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	248	337	332	175	519	-----	-----	-----
Secchi Depth (in.)	1	25	25	24	14	60	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	216	31	20	1	108	10(4)	171	79%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).
(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

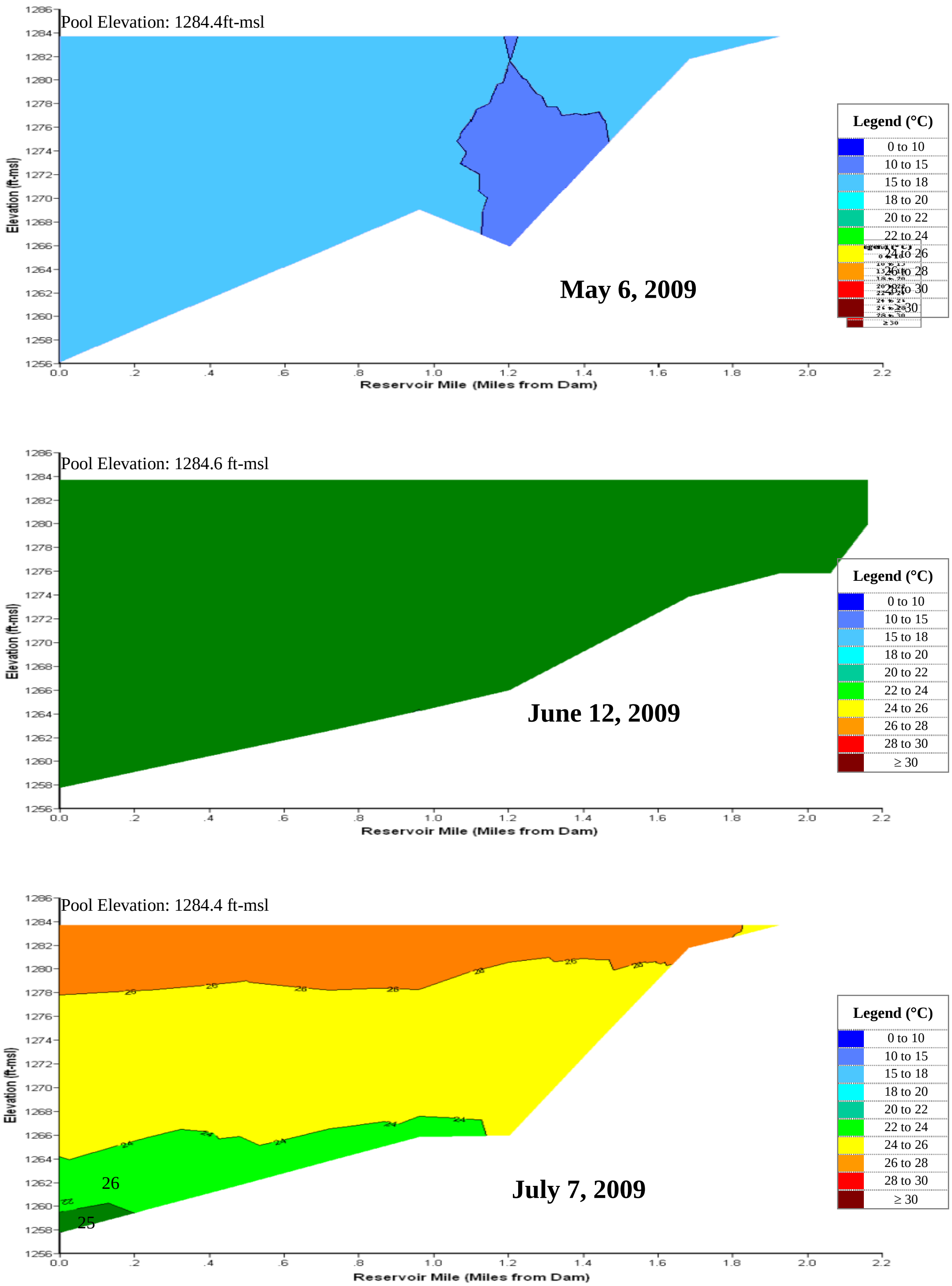
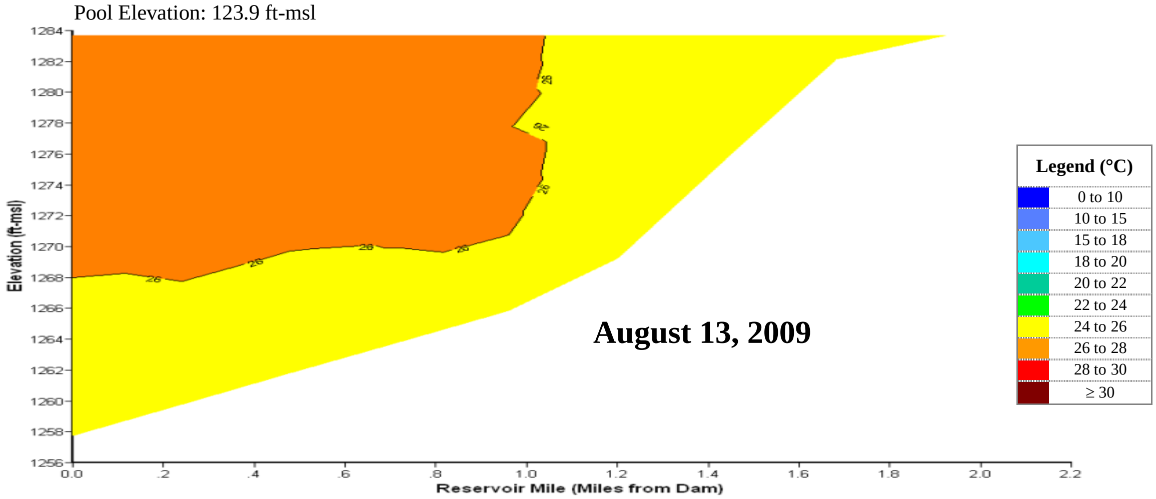


Plate 92. Longitudinal water temperature (°C) contour plots of Branched Oak Reservoir through the north arm based on depth-profile water temperatures measured at sites BOKLKND1 and BOKLKMLN1 in 2009.



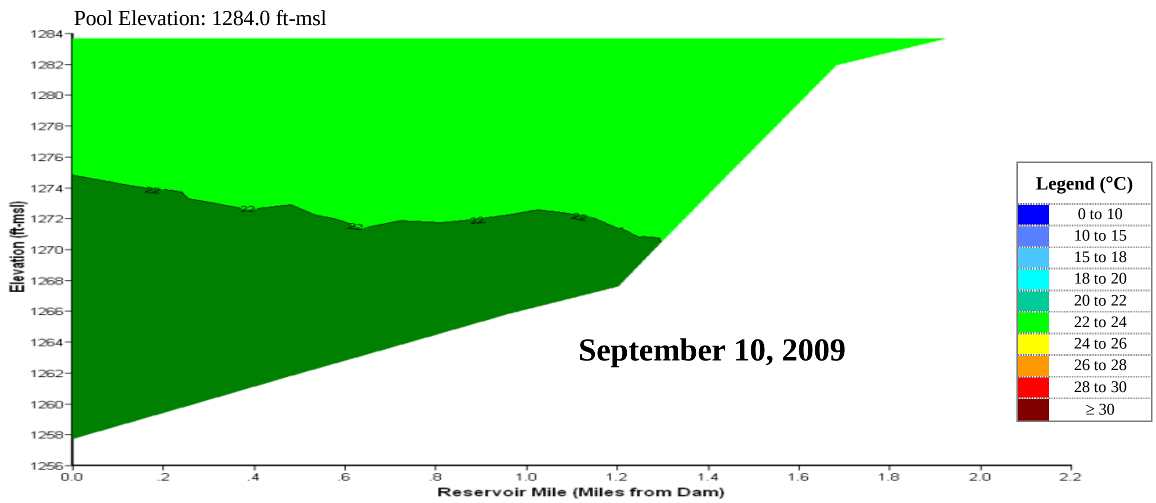


Plate 92. (Continued).

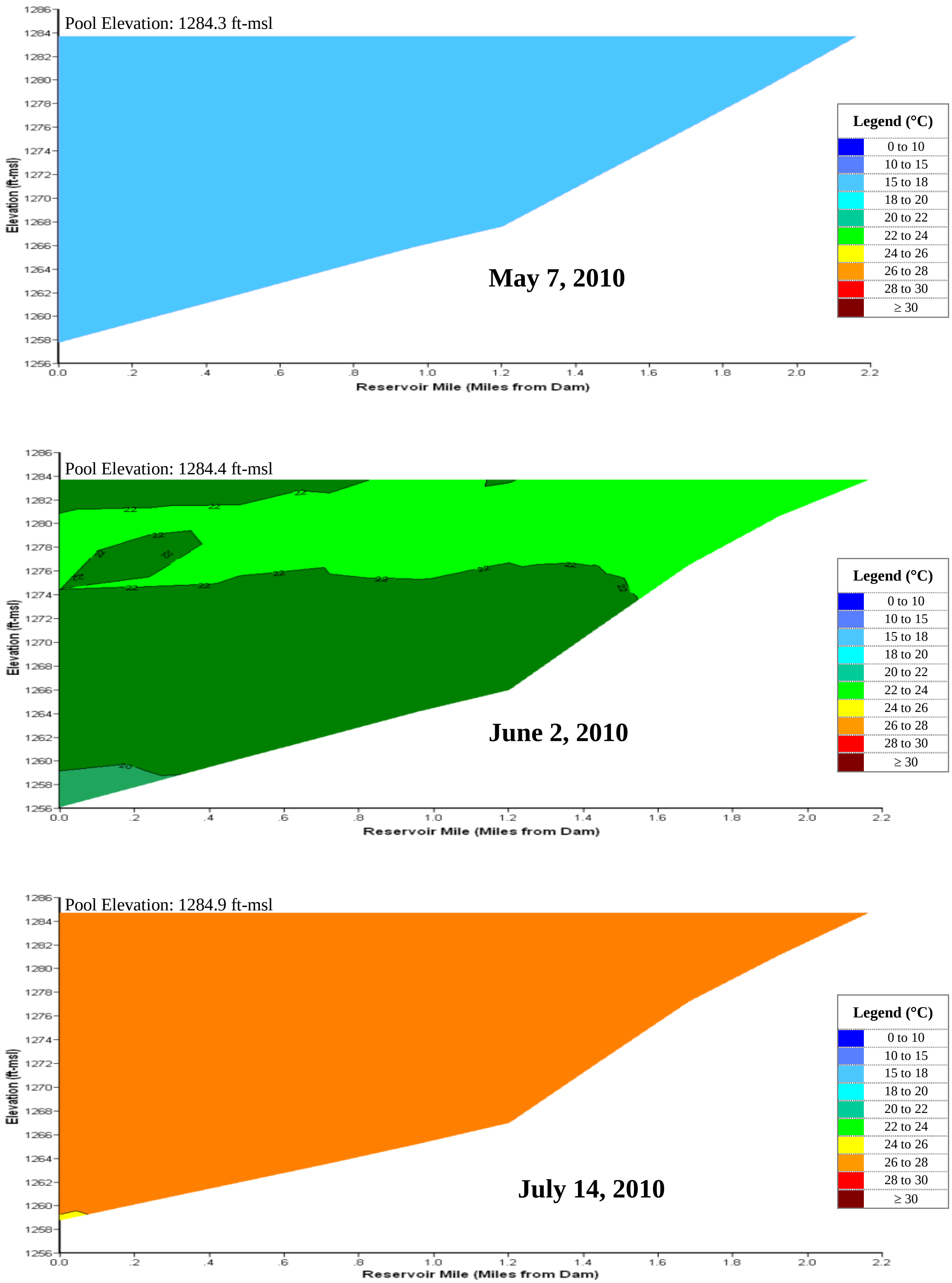
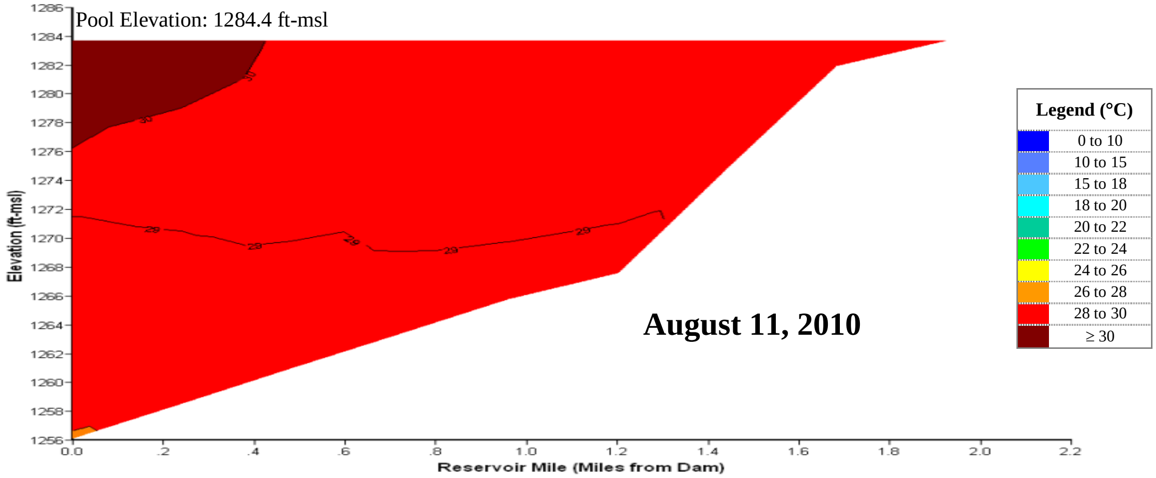


Plate 93. Longitudinal water temperature (°C) contour plots of Branched Oak Reservoir through the north arm based on depth-profile water temperatures measured at sites BOKLKND1, BOKLKMLN1, and BOKLKUPN1 in 2010.



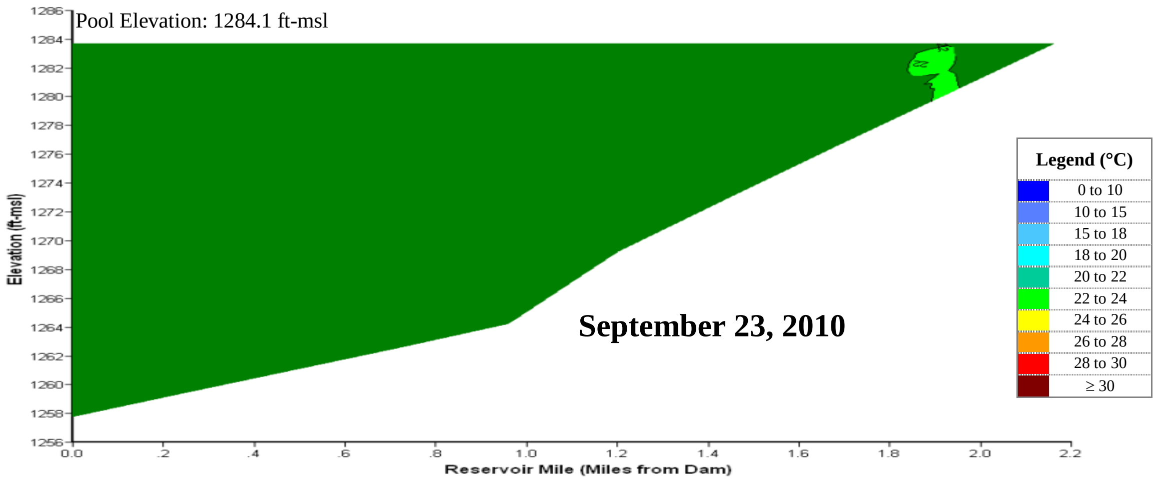


Plate 93. (Continued).

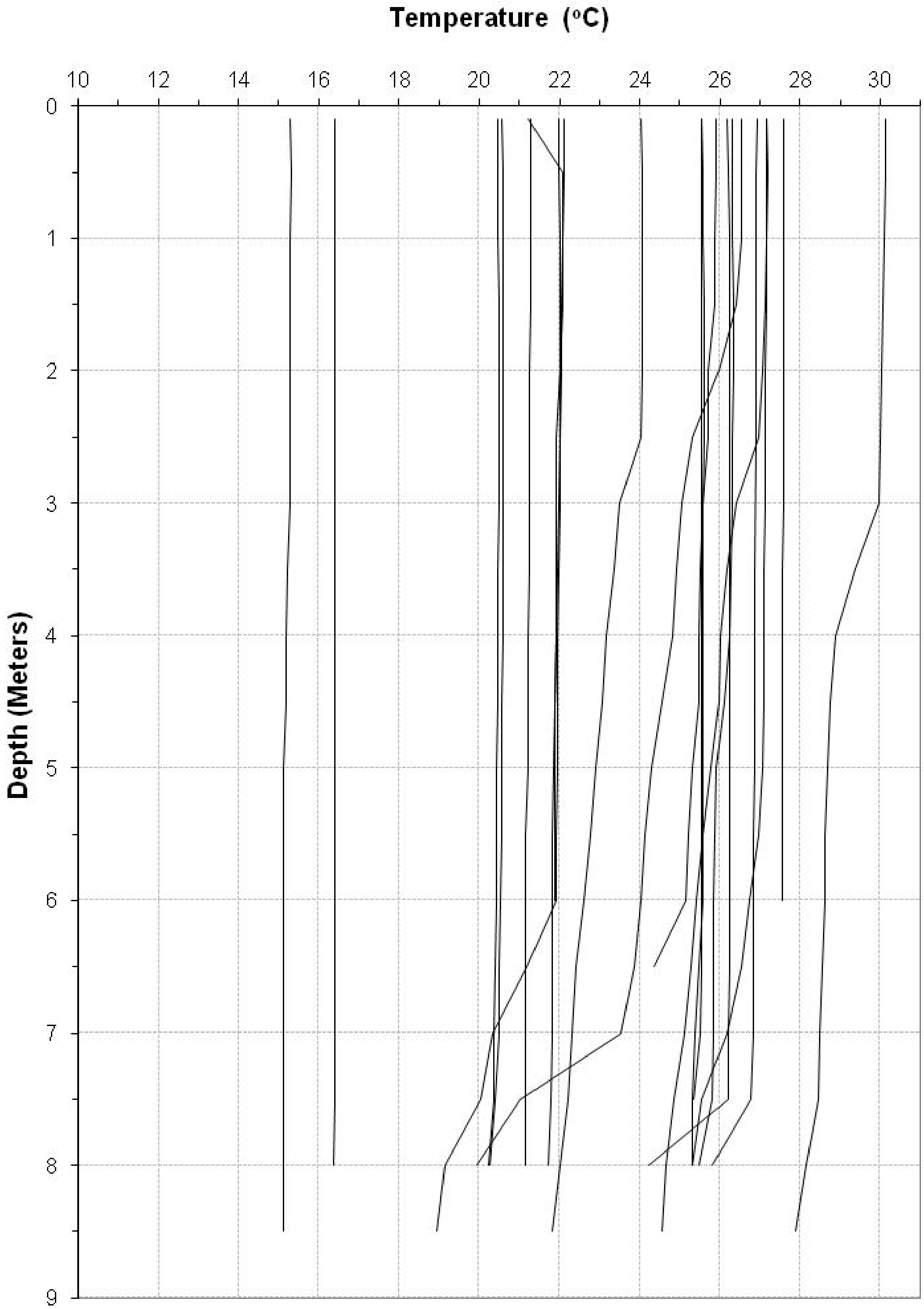


Plate 94. Temperature depth profiles for Branched Oak Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., BOKLKND1) during the summer over the 5-year period of 2006 through 2010.

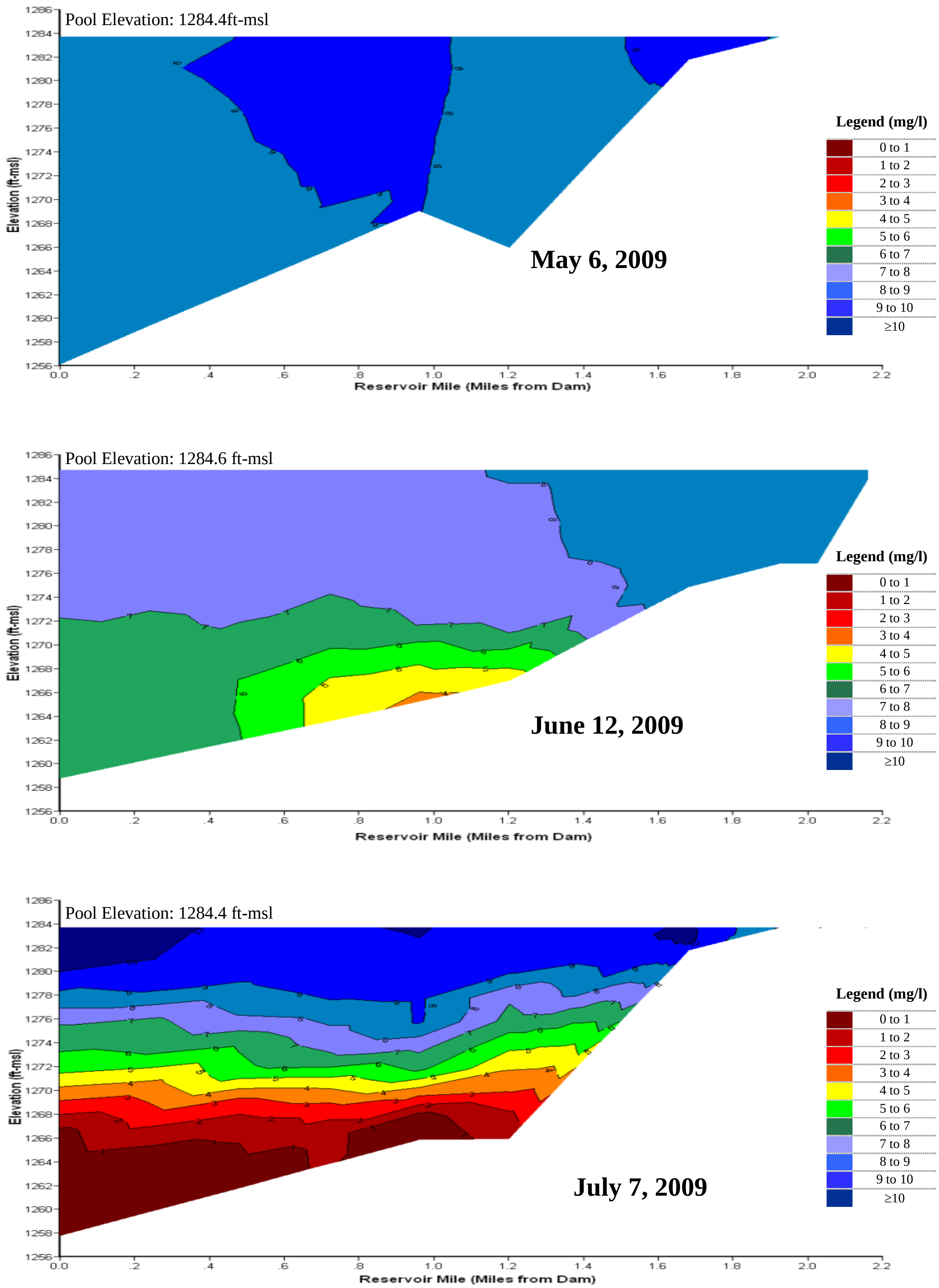
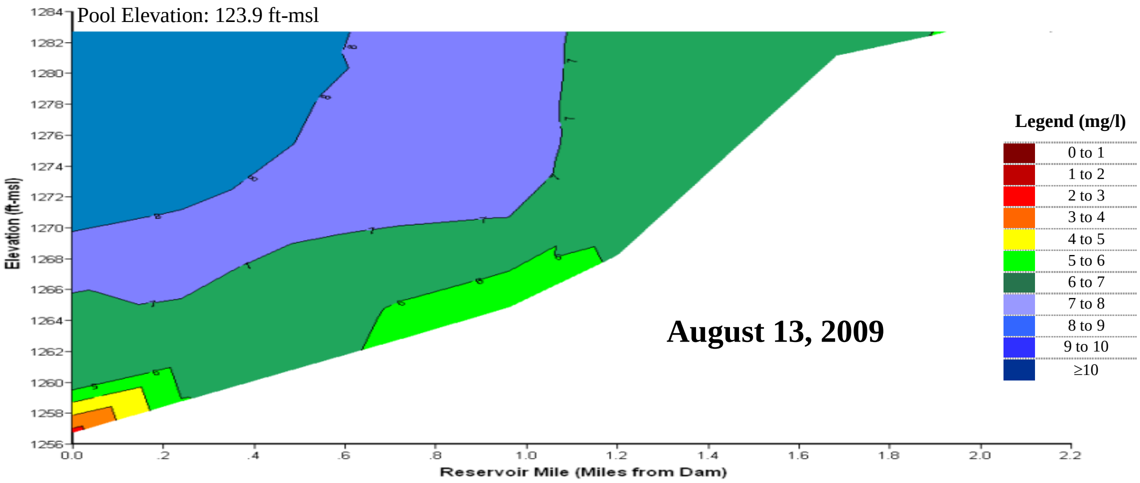


Plate 95. Longitudinal dissolved oxygen (mg/l) contour plots of Branched Oak Reservoir through the north arm based on depth-profile dissolved oxygen concentrations measured at sites BOKLKND1 and BOKLKMLN1 in 2009.



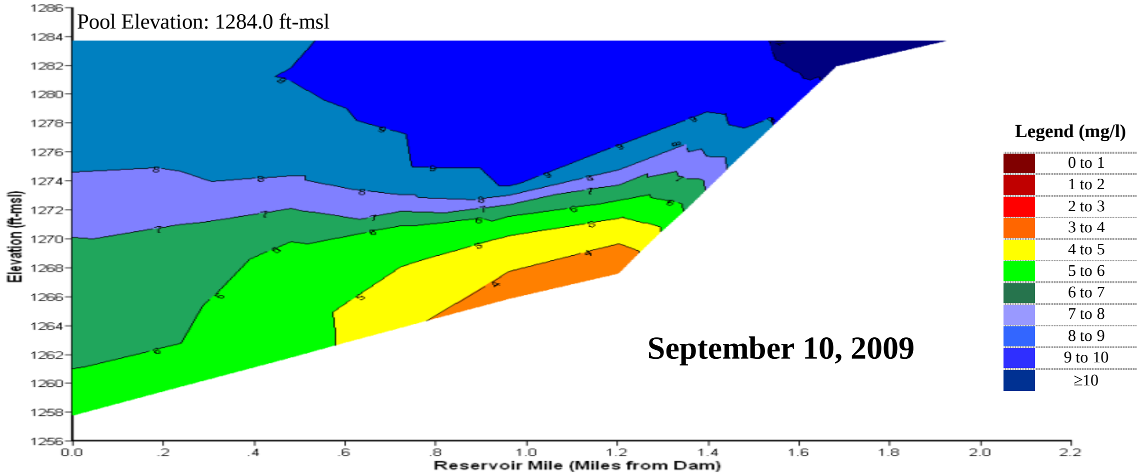


Plate 95. (Continued).

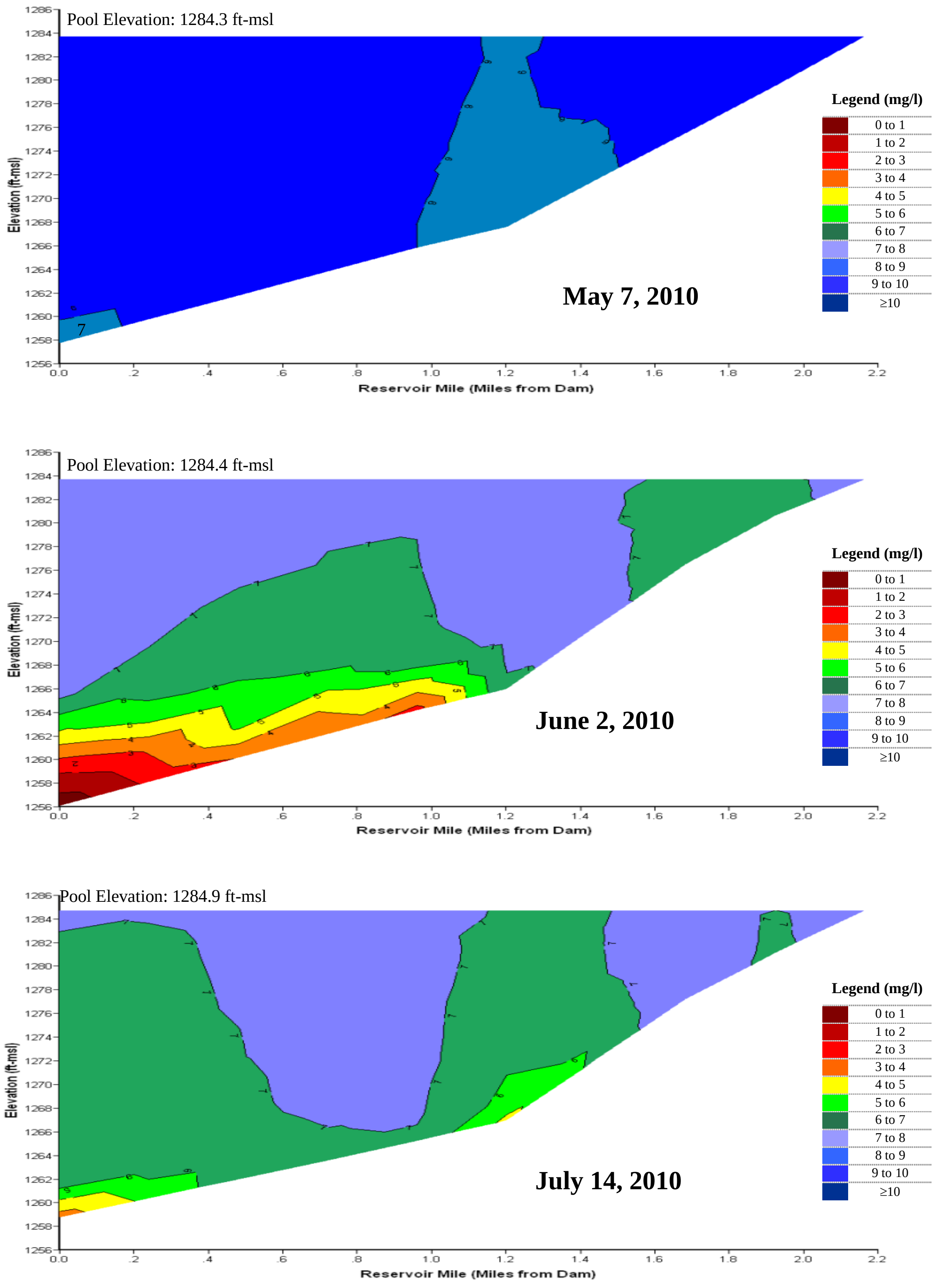
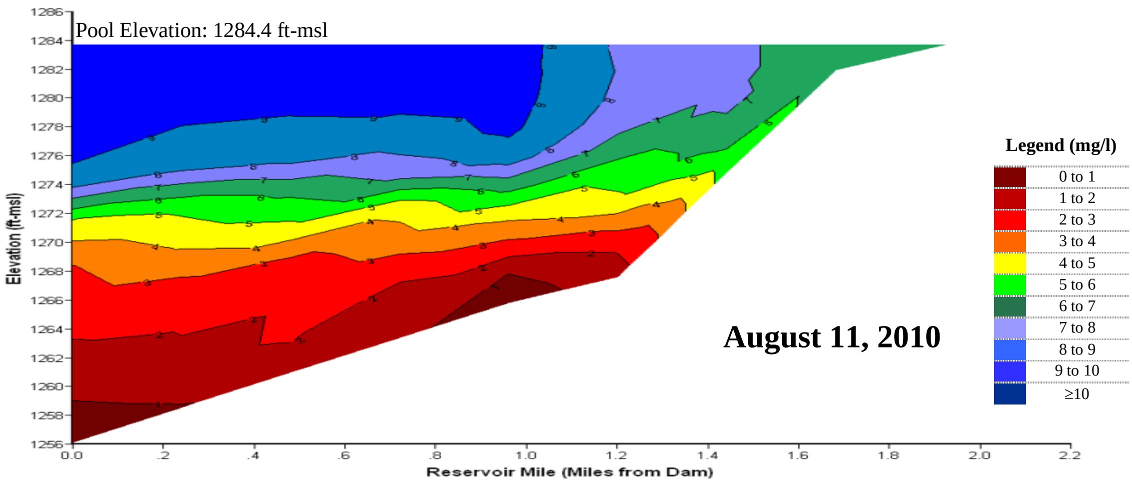


Plate 96. Longitudinal dissolved oxygen (mg/l) contour plots of Branched Oak Reservoir through the north arm based on depth-profile dissolved oxygen concentrations measured at sites BOKLKND1, BOKLKMLN1, and BOKLKUPN1 in 2010.



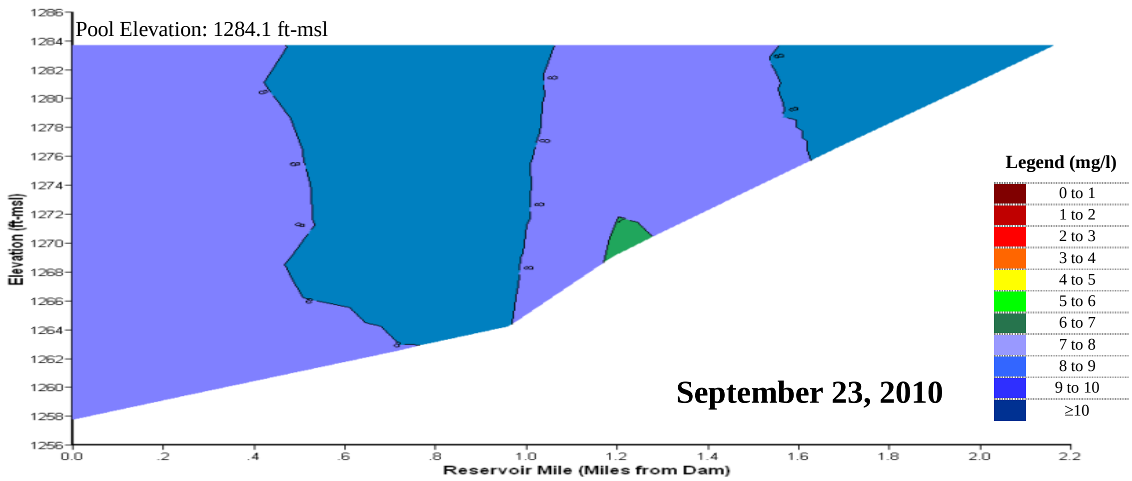


Plate 96. (Continued).

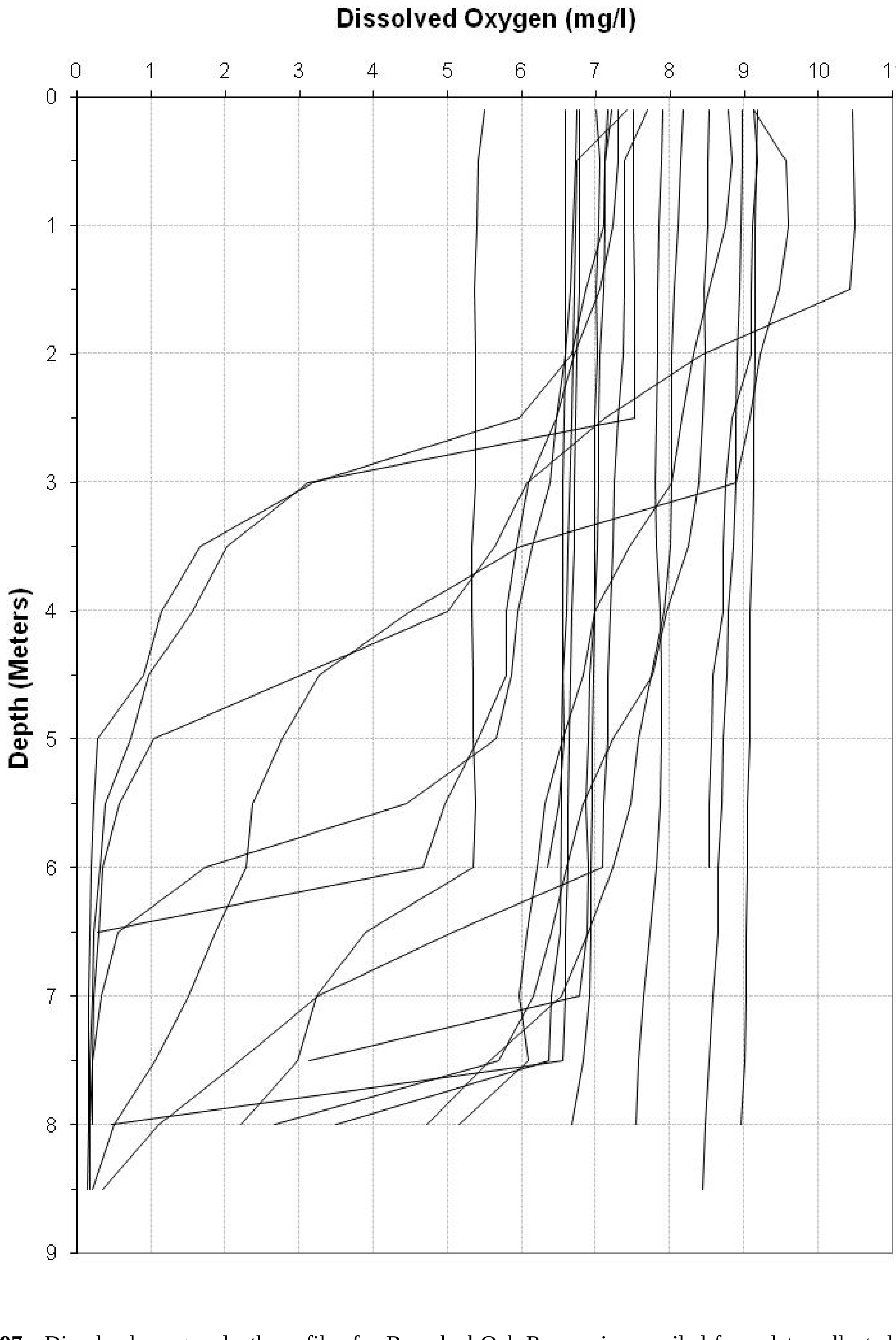


Plate 97. Dissolved oxygen depth profiles for Branched Oak Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., BOKLKND1) during the summer over the 5-year period of 2006 through 2010.

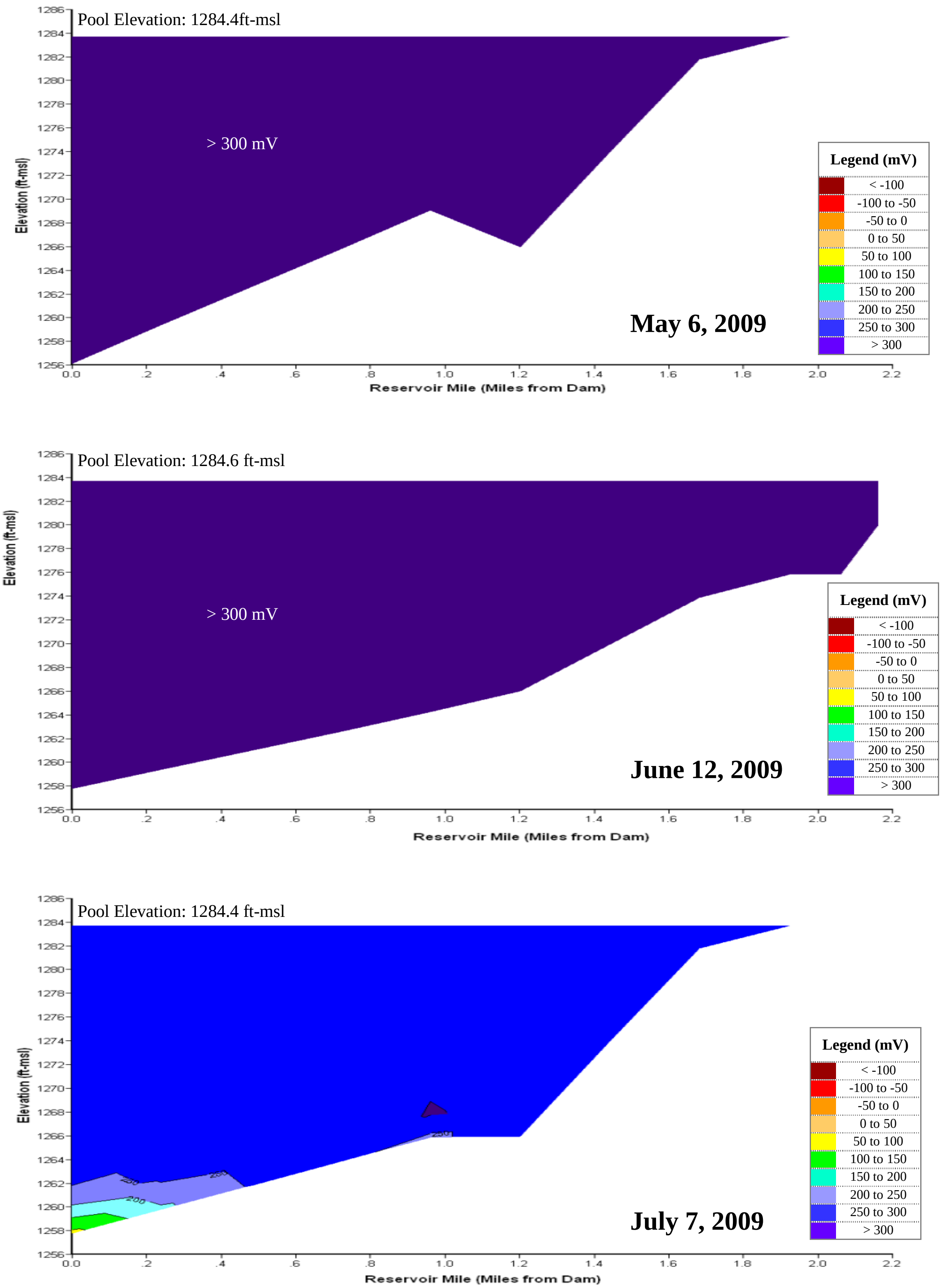
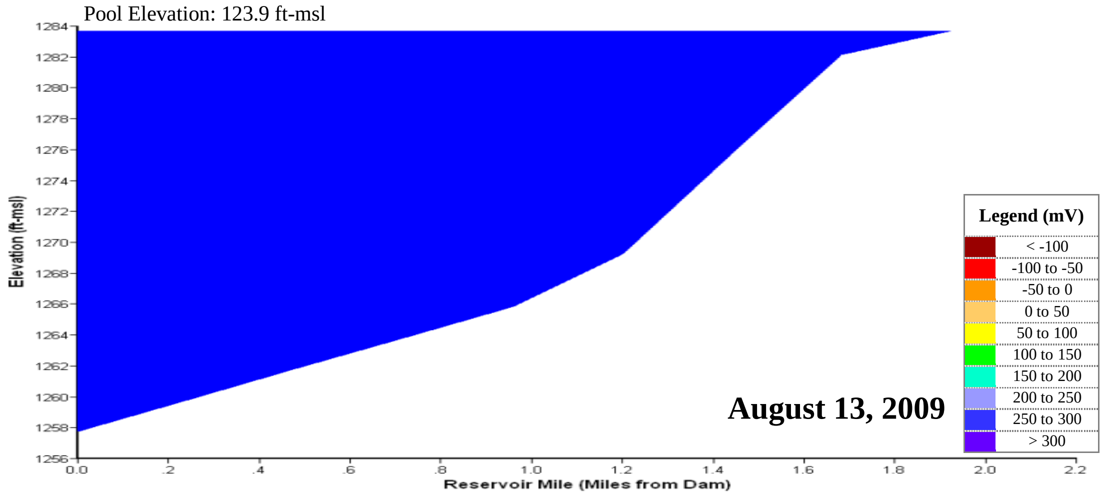


Plate 98. Longitudinal oxidation-reduction potential (mV) contour plots of Branched Oak Reservoir through the north arm based on depth-profile ORP levels measured at sites BOKLKND1 and BOKLKMLN1 in 2009.



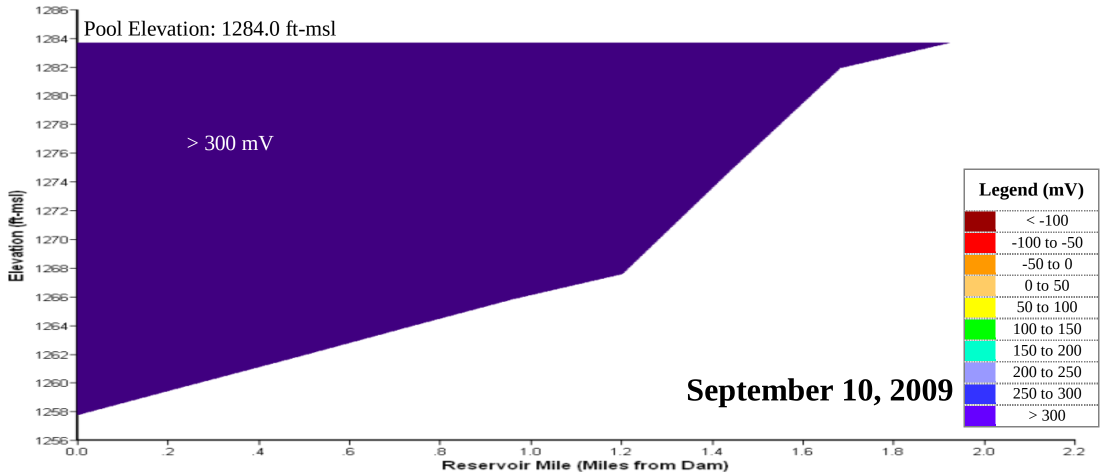


Plate 98. (Continued).

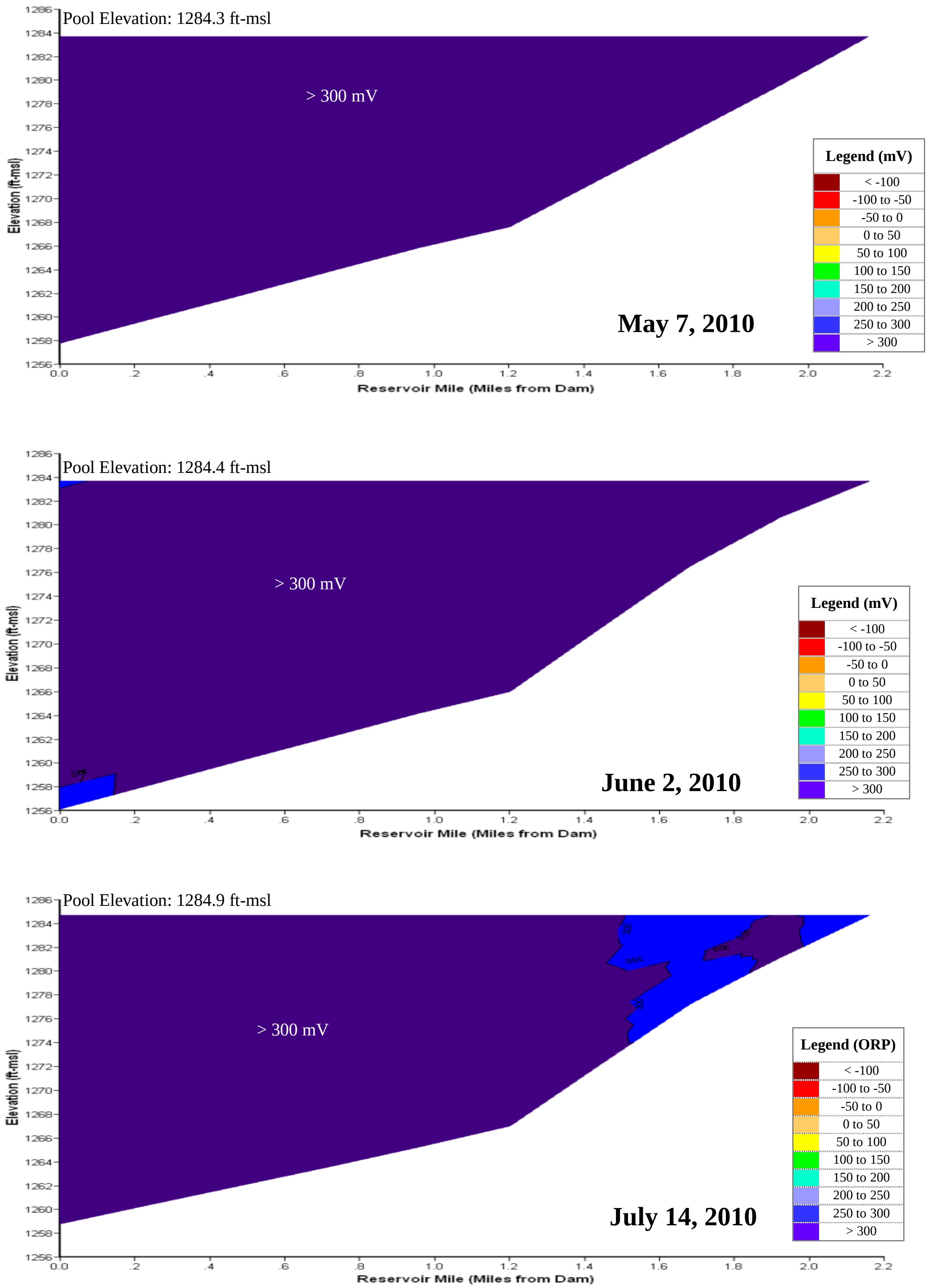
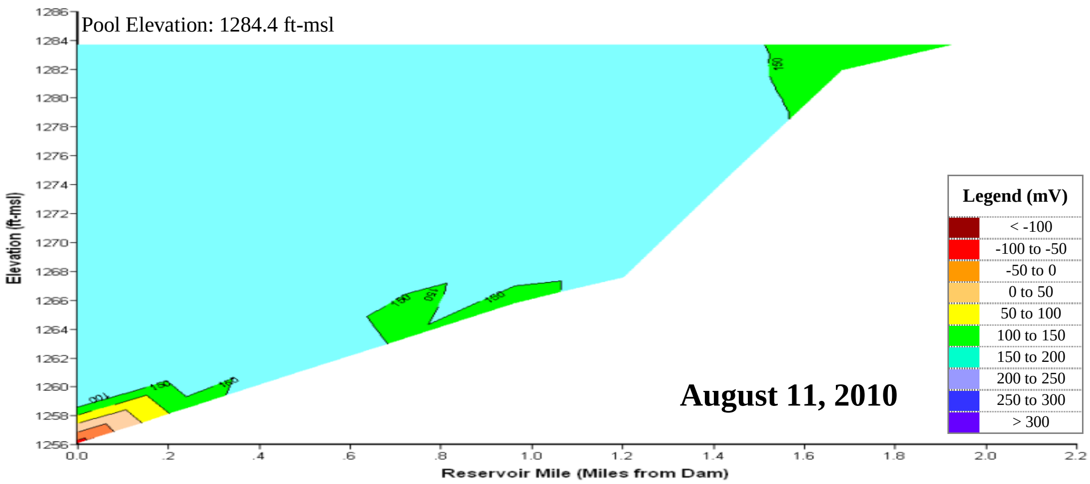


Plate 99. Longitudinal oxidation-reduction potential (mV) contour plots of Branched Oak Reservoir through the north arm based on depth-profile ORP levels measured at sites BOKLKND1, BOKLKMLN1, and BOKLKUPN1 in 2010.



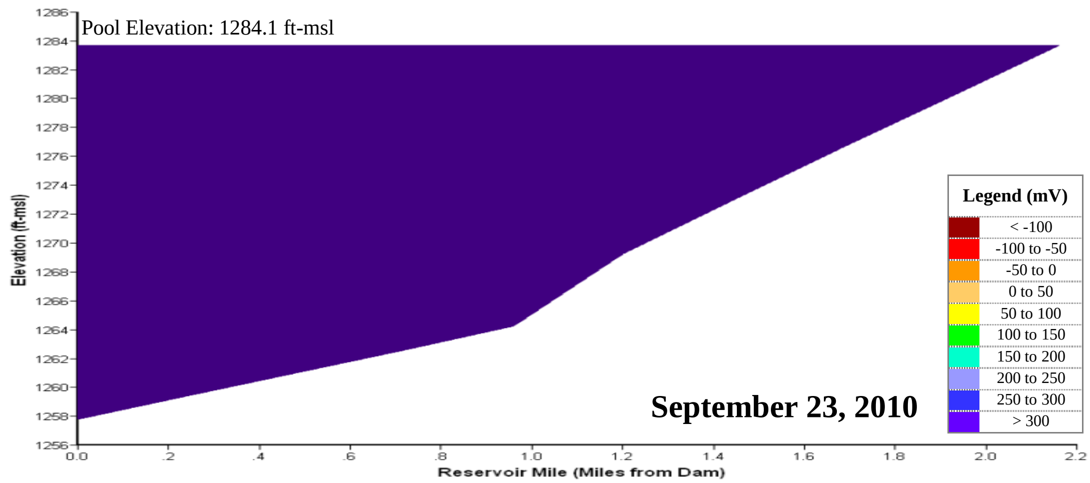


Plate 99. (Continued).

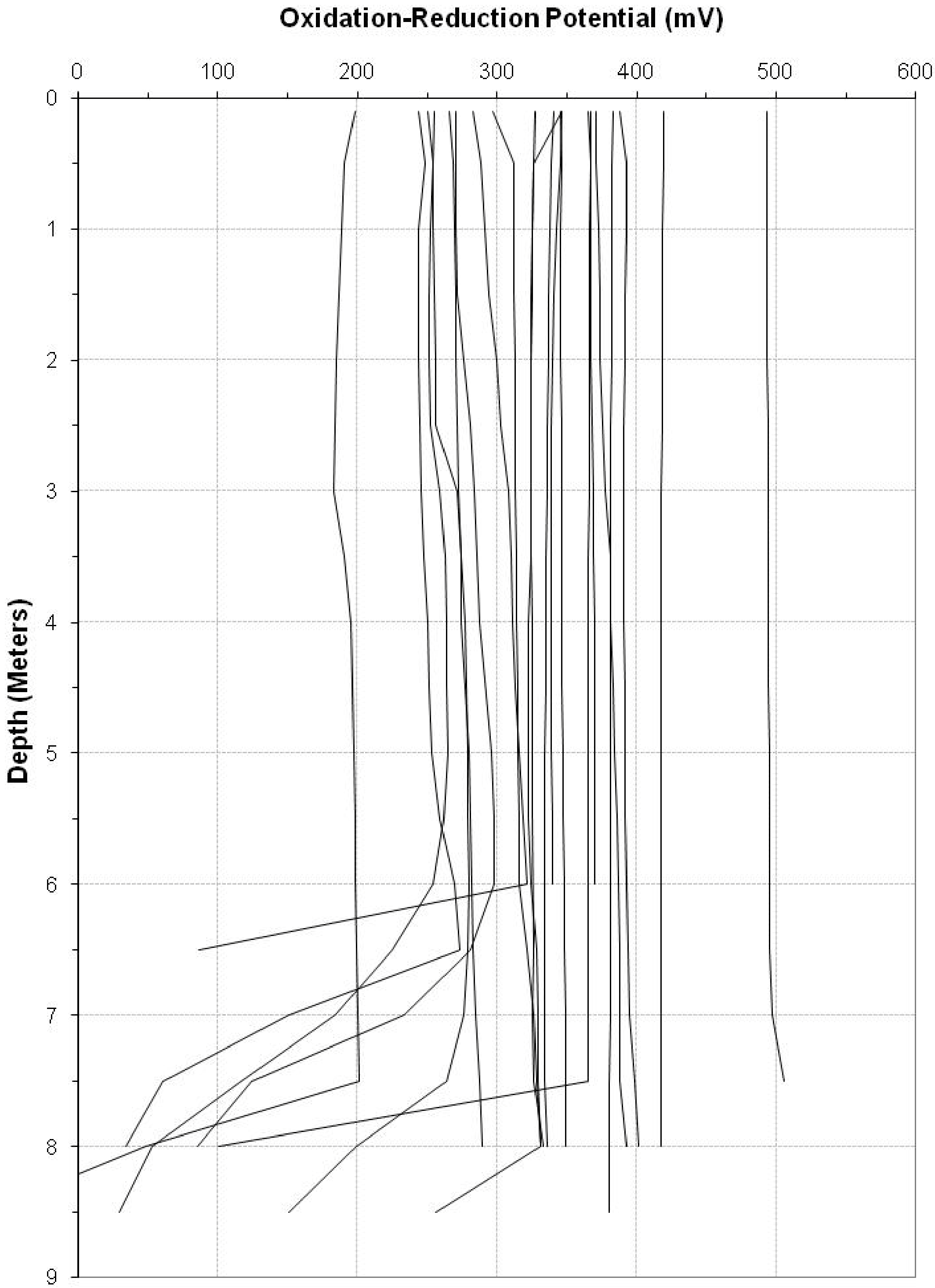
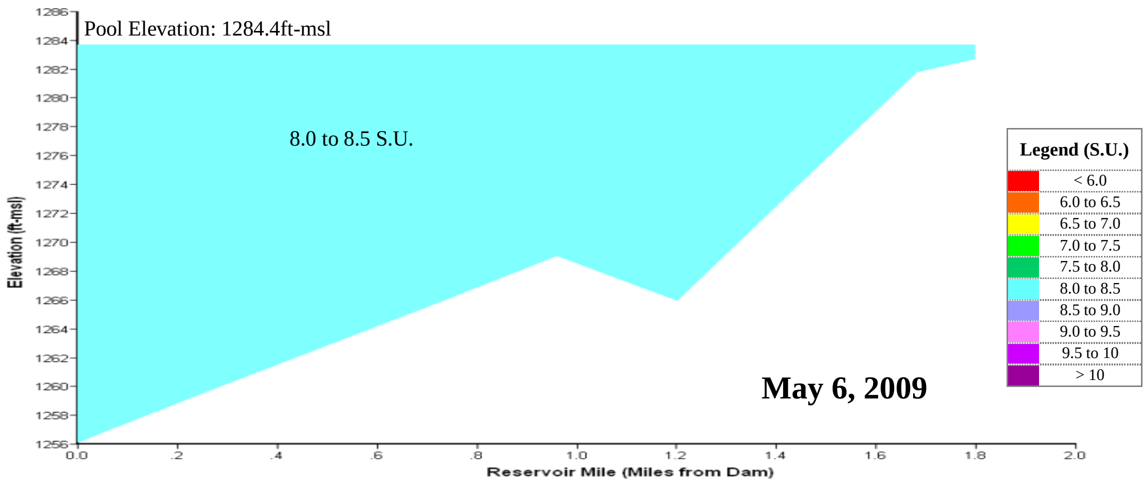
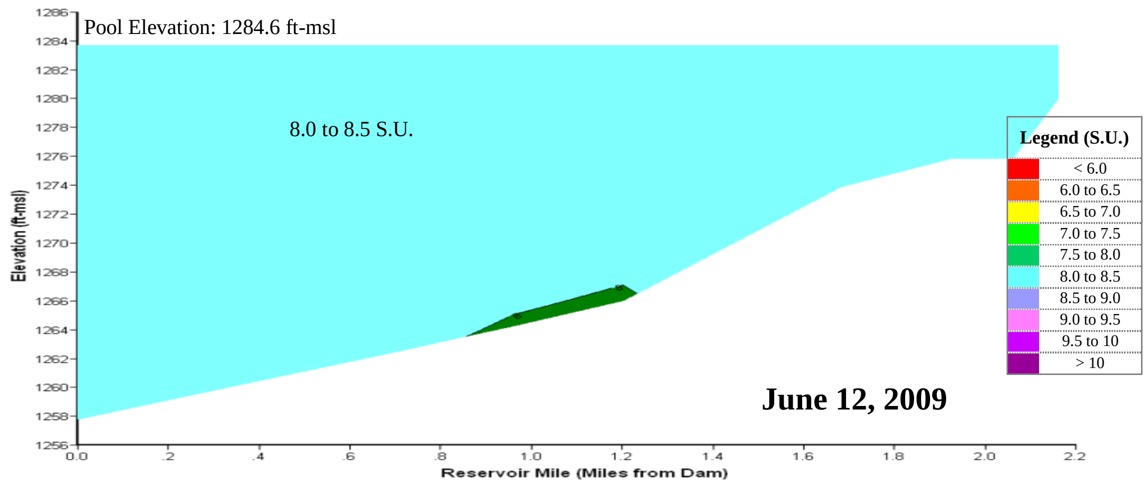


Plate 100. Oxidation-reduction potential depth profiles for Branched Oak Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., BOKLKND1) during the summer over the 5-year period of 2006 through 2010.





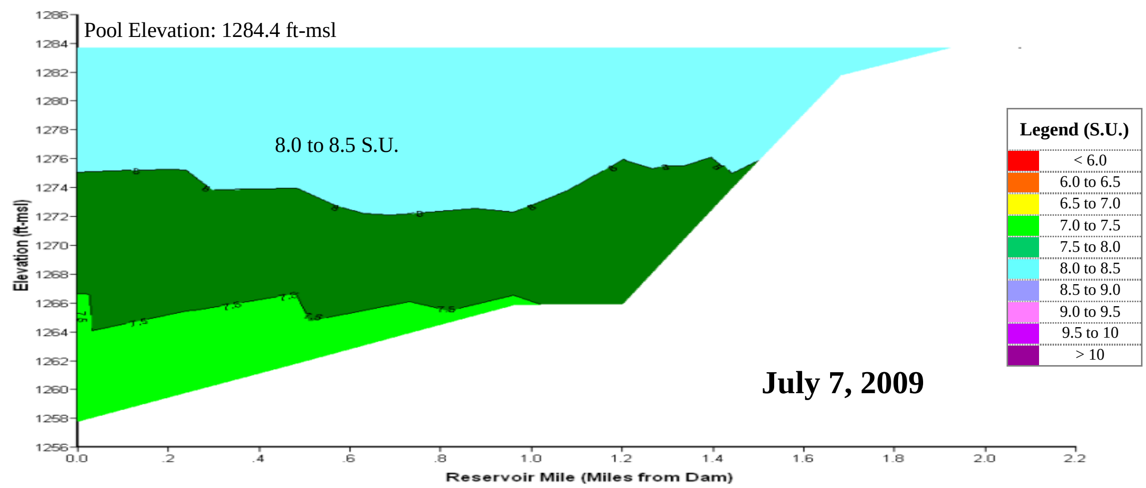
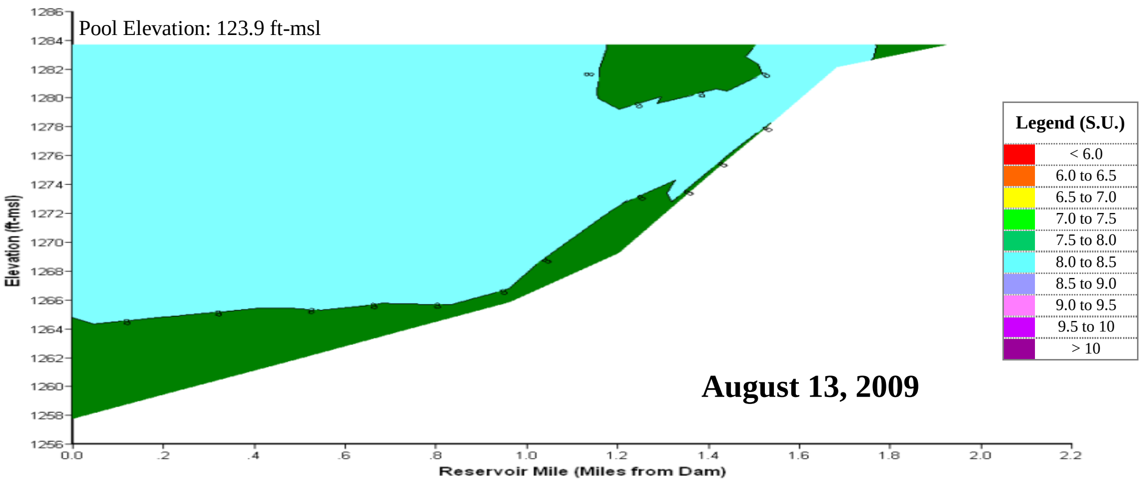


Plate 101. Longitudinal pH (S.U.) contour plots of Branched Oak Reservoir through the north arm based on depth-profile pH levels measured at sites BOKLKND1 and BOKLKMLN1 in 2009.



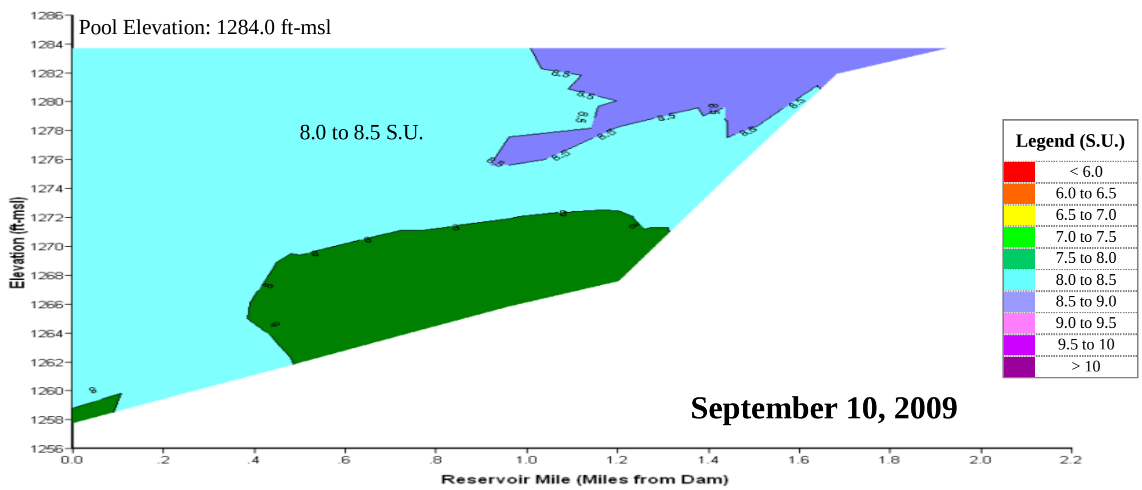


Plate 101. (Continued).

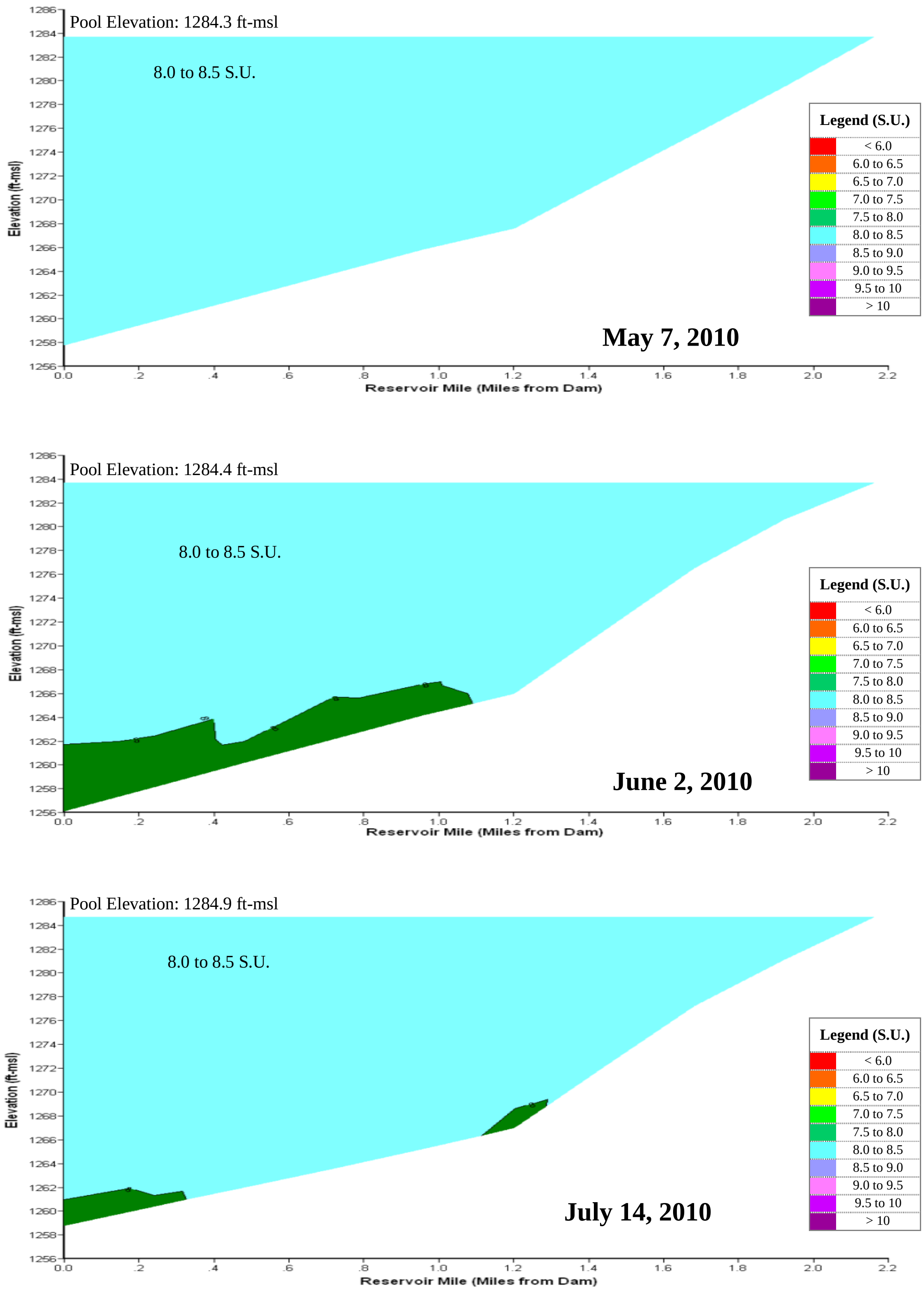
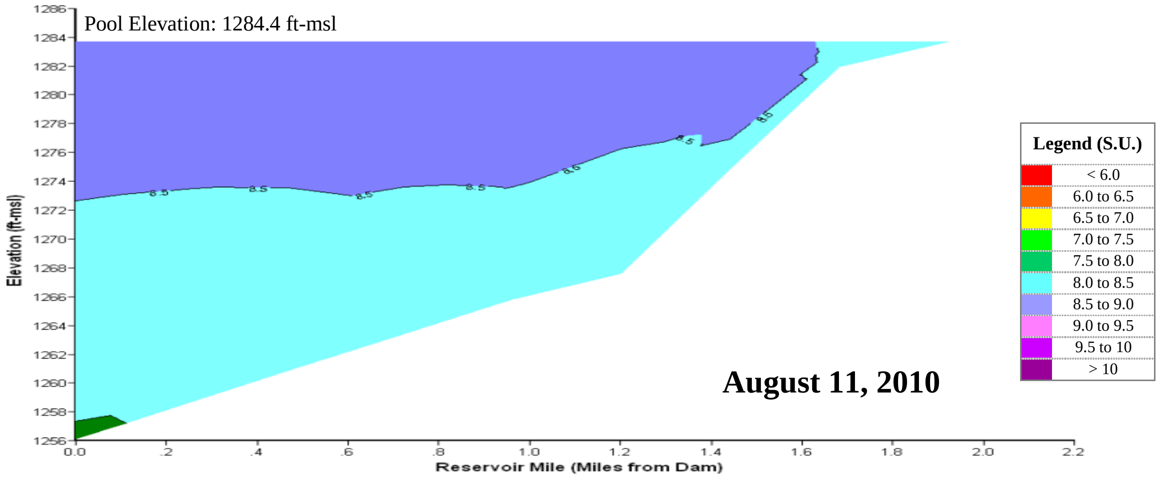


Plate 102. Longitudinal pH (S.U.) contour plots of Branched Oak Reservoir through the north arm based on depth-profile pH levels measured at sites BOKLKND1, BOKLKMLN1, and BOKLKUPN1 in 2008.



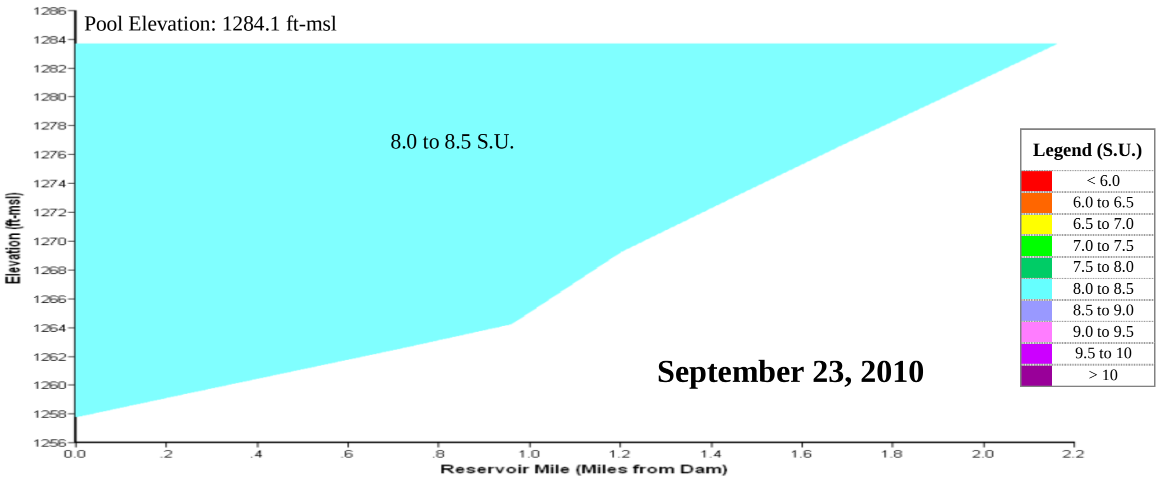


Plate 102. (Continued).

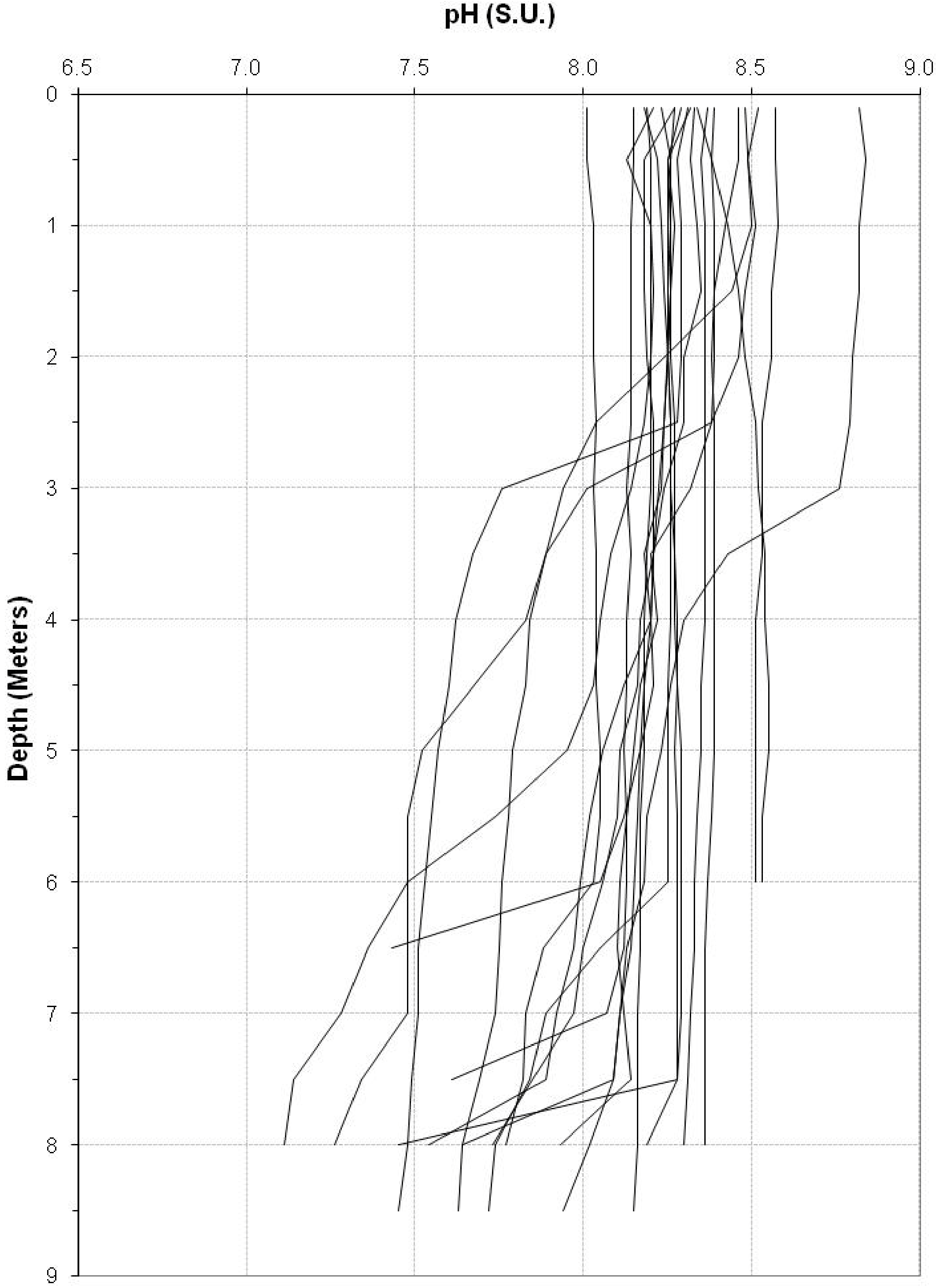


Plate 103. pH depth profiles for Branched Oak Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., BOKLKND1) during the summer over the 5-year period of 2006 through 2010.

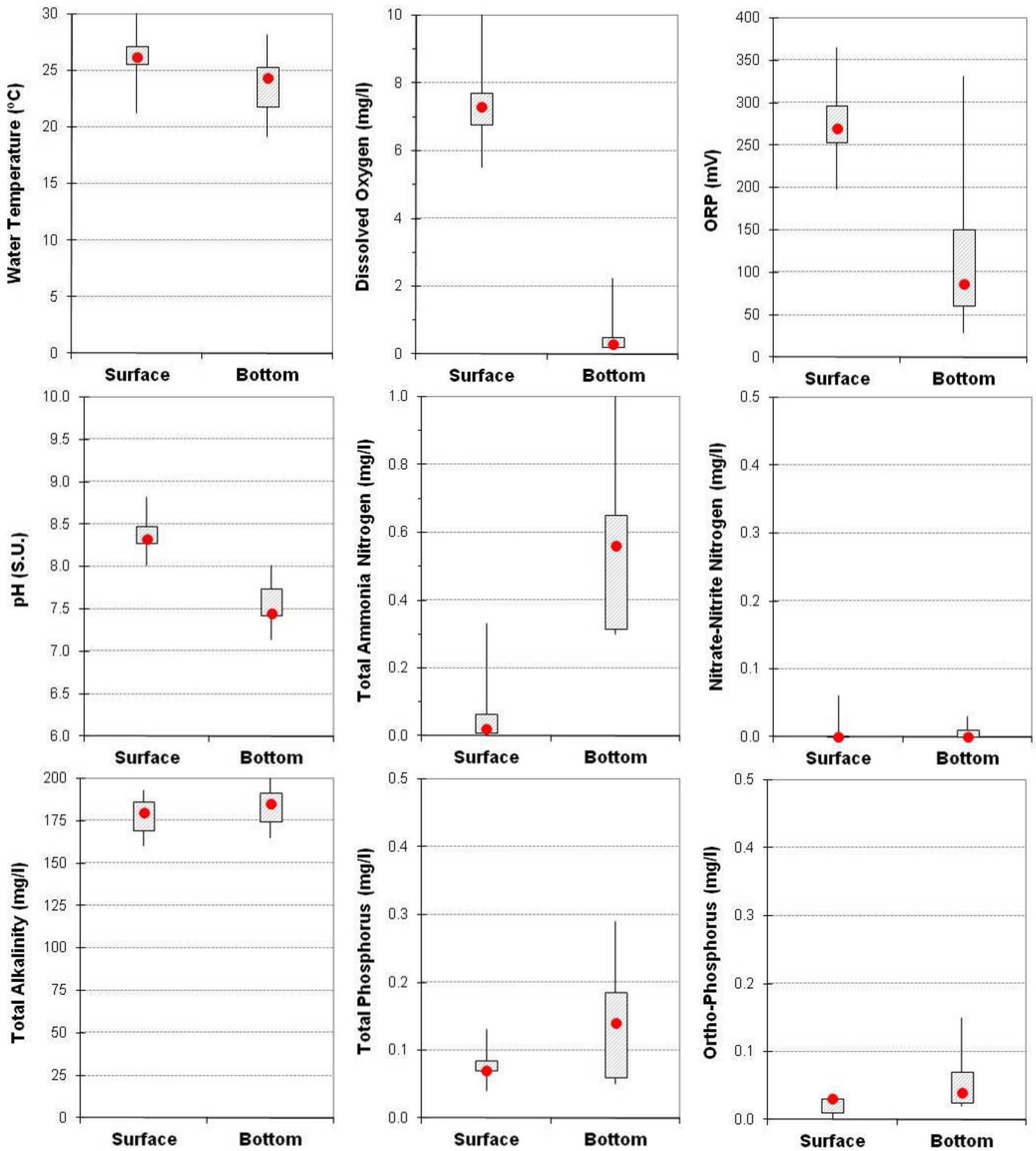


Plate 104. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, alkalinity, total ammonia nitrogen, nitrate-nitrite nitrogen, total phosphorus, and ortho-phosphorus measured in Branched Oak Reservoir when summer hypoxic conditions were present during the 5-year period 2006 through 2010. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

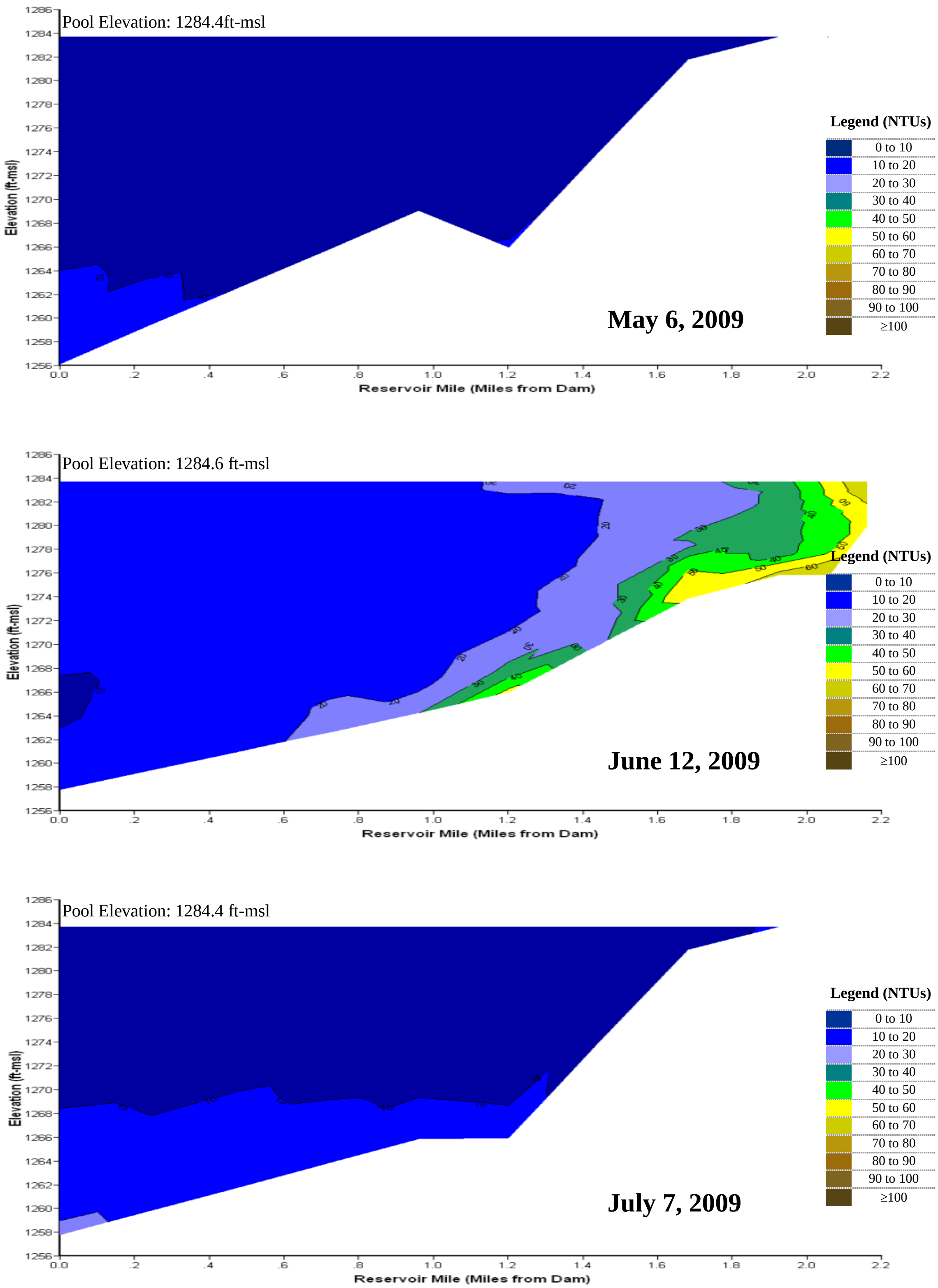
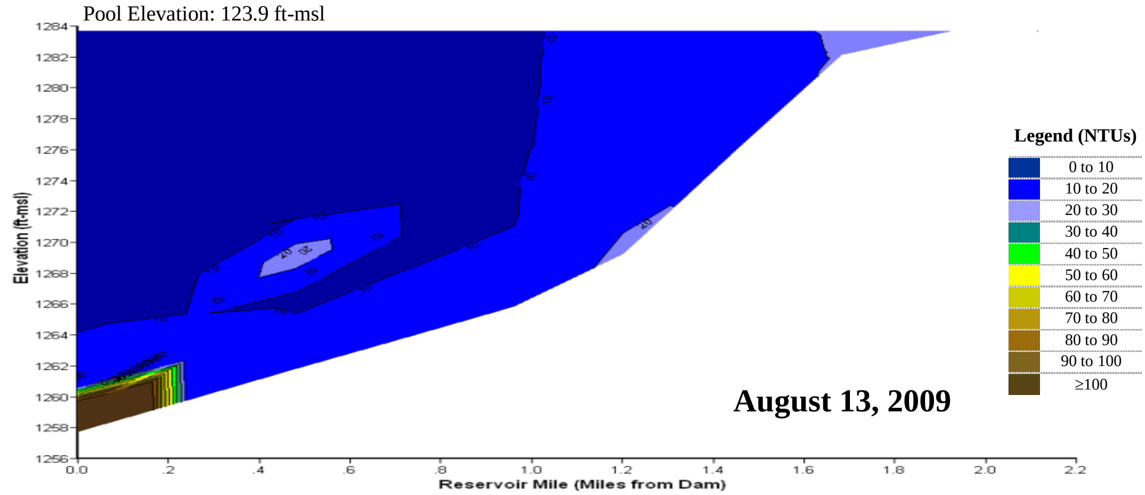


Plate 105. Longitudinal turbidity (NTU) contour plots of Branched Oak Reservoir through the north arm based on depth-profile turbidity levels measured at sites BOKLKND1 and BOKLKMLN1 in 2009.



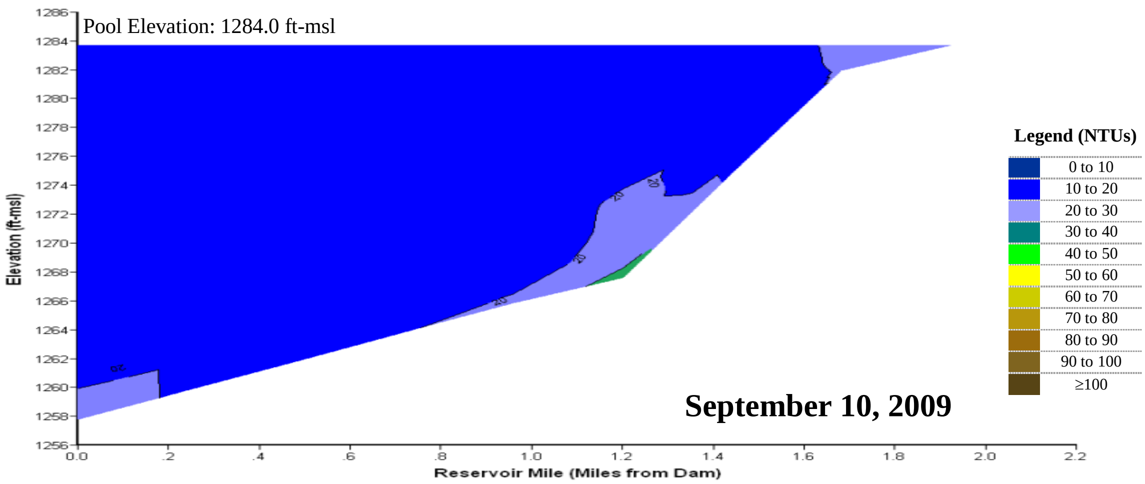
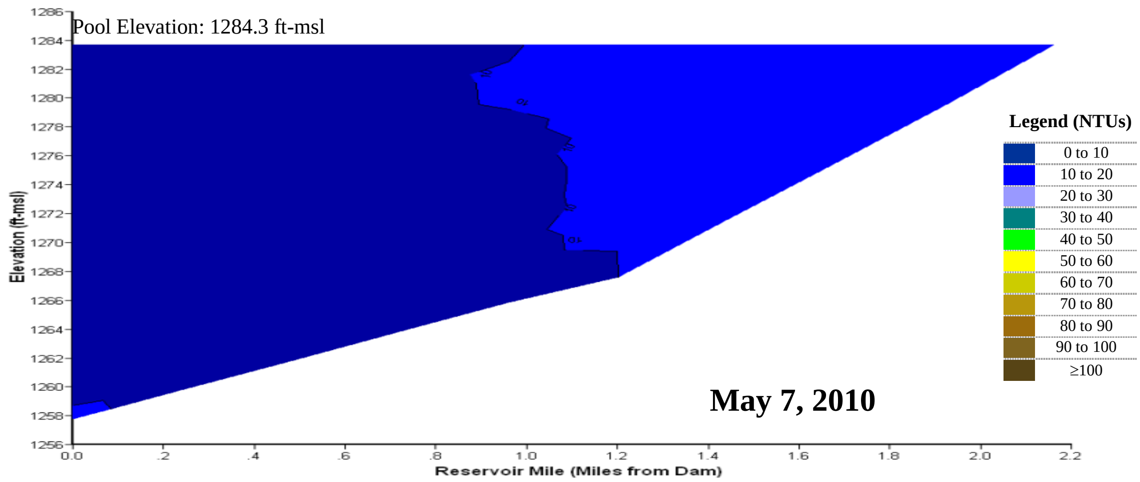
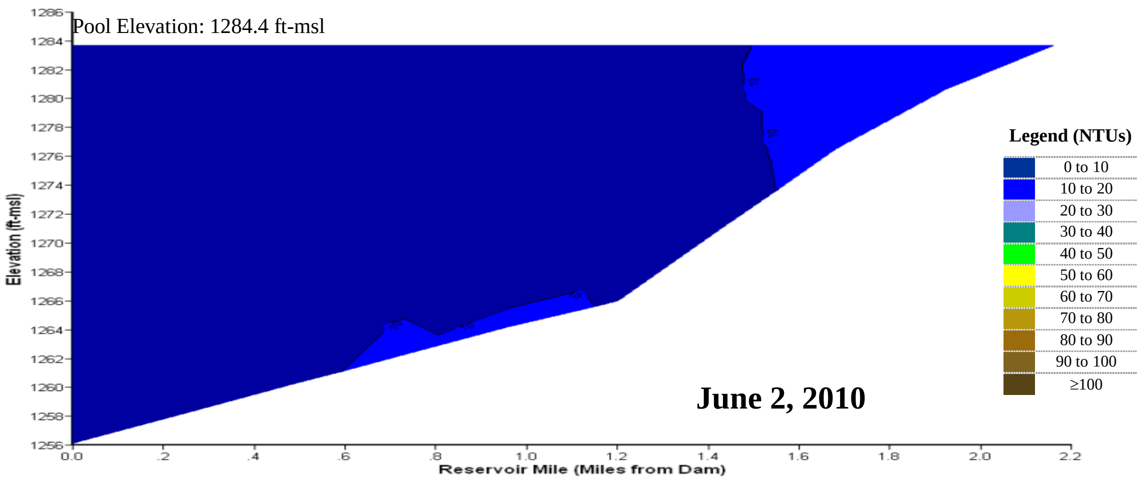


Plate 105. (Continued).





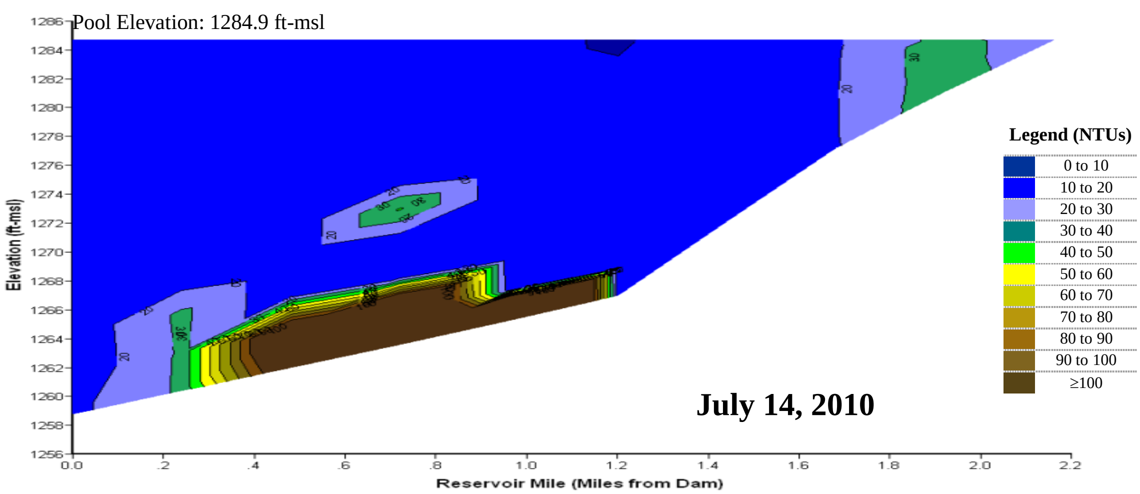
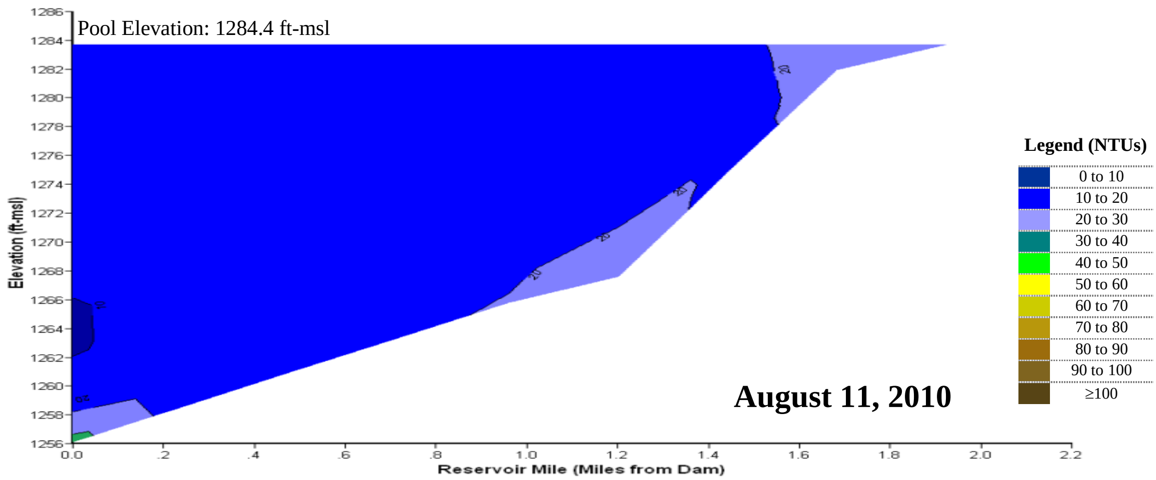


Plate 106. Longitudinal turbidity (NTU) contour plots of Branched Oak Reservoir through the north arm based on depth-profile turbidity levels measured at sites BOKLKND1, BOKLKMLN1, and BOKLKUPN1 in 2010.



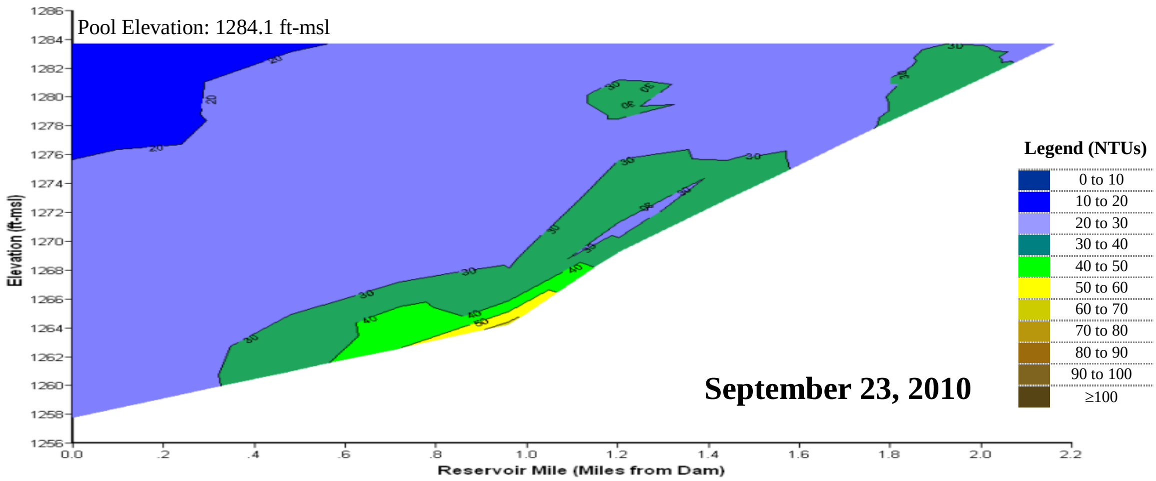


Plate 106. (Continued).

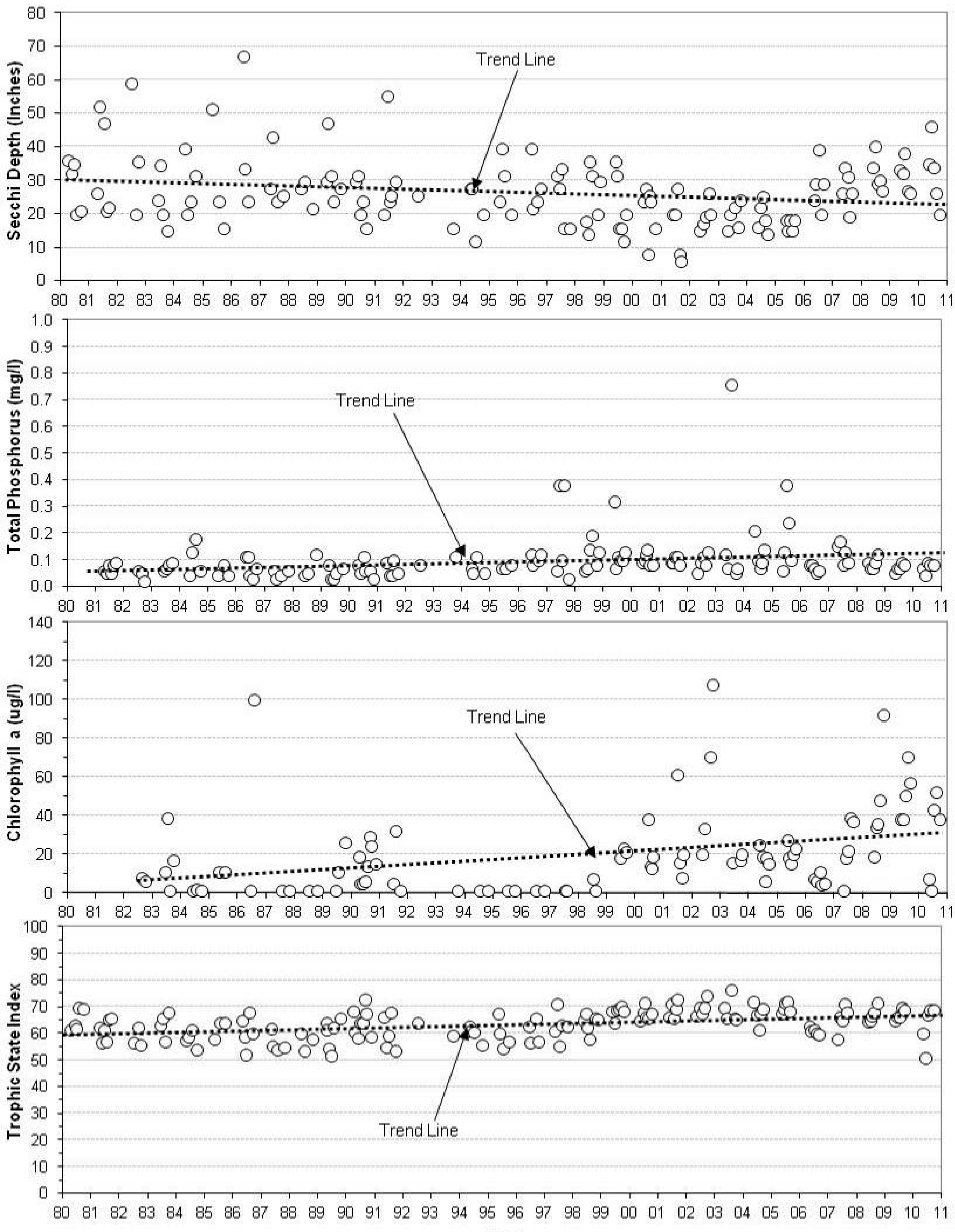


Plate 107. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Branched Oak Reservoir at the near-dam, ambient site (i.e., site BOKLKND1) over the 31-year period of 1980 through 2010.

Plate 108. Summary of runoff water quality conditions monitored in the main north tributary inflow to Branched Oak Reservoir at monitoring site BOKNFNRT1 during the 5-year period 2004 through 2008**.** Runoff conditions have not been monitored since 2008.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Kjeldahl N, Total (mg/l)	0.1	7	5.0	3.2	1.0	17.0	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	7	0.81	0.79	0.25	1.30	100(3)	0	0%
Phosphorus, Total (mg/l)	0.02	7	1.56	0.88	0.41	5.50	-----	-----	-----
Suspended Solids, Total (mg/l)	4	7	904	372	38	4,260	-----	-----	-----
Acetochlor, Total (ug/l)(C)	0.05	2	0.81	0.81	0.73	0.88	-----	-----	-----
Alachlor, Total (ug/l)(C)	0.05	2	0.10	0.10	0.09	0.11	760(1), 76(2)	0	0%
Atrazine, Total (ug/l)(C)	0.05	4	4.82	2.70	1.43	12.43	330(1), 12(2)	0, 1	0%, 25%
Metolachlor, Total (ug/l)(C)	0.05	4	0.35	0.19	0.11	0.89	390(1), 100(2)	0	0%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Acute criterion for aquatic life.
(2) Chronic criterion for aquatic life.
(3) Agricultural criteria for surface waters.
(C) Immunoassay analysis.

Plate 109. Summary of runoff water quality conditions monitored in the main west tributary inflow to Branched Oak Reservoir at monitoring site BOKNFWST1 during the 5-year period 2004 through 2008**.** Runoff conditions have not been monitored since 2008.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Kjeldahl N, Total (mg/l)	0.1	7	4.2	3.0	1.5	12.0	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	7	1.42	0.62	0.16	6.60	100(3)	0	0%
Phosphorus, Total (mg/l)	0.02	7	1.03	0.91	0.40	2.20	-----	-----	-----
Suspended Solids, Total (mg/l)	4	7	699	580	129	1,480	-----	-----	-----
Acetochlor, Total (ug/l)(C)	0.05	2	1.33	1.33	0.32	2.34	-----	-----	-----
Alachlor, Total (ug/l)(C)	0.05	2	1.39	1.39	0.51	2.27	760(1), 76(2)	0	0%
Atrazine, Total (ug/l)(C)	0.05	4	2.94	3.21	0.64	4.72	330(1), 12(2)	0	0%
Metolachlor, Total (ug/l)(C)	0.05	4	-----	0.56	n.d.	2.03	390(1), 100(2)	0	0%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Acute criterion for aquatic life.
(2) Chronic criterion for aquatic life.
(3) Agricultural criteria for surface waters.
(C) Immunoassay analysis.

Plate 110. Summary of water quality conditions monitored in Conestoga Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site CONLKND1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	25	1231.4	1232.6	1225.80	1234.1	-----	-----	-----
Water Temperature (°C)	0.1	203	23.7	24.4	15.5	33.0	32[1]	2	1%
Dissolved Oxygen (mg/l)	0.1	203	7.0	7.3	0.2	14.4	≥ 5[2]	31	15%
Dissolved Oxygen (% Sat.)	0.1	190	85.5	86.4	2.7	189.0	-----	-----	-----
Specific Conductance (umho/cm)	1	190	440.6	416.3	317.0	636.2	2,000[3]	0	0%
pH (S.U.)	0.1	190	8.1	8.1	7.1	9.3	≥6.5 & ≤9.0[1]	2	1%
Turbidity (NTUs)	1	190	45	26	7	646	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	190	303	301	-104	459	-----	-----	-----
Secchi Depth (in.)	1	25	20	19	9	36	-----	-----	-----
Alkalinity, Total (mg/l)	7	50	137	129	92	212	20[1]	0	0%
Ammonia, Total (mg/l)	0.02	50	-----	0.16	n.d.	0.92	6.95 [4,5], 1.11 [4,6]	0, 0	0%, 0%
Chlorophyll *a* (ug/l) – Field Probe	1	155	28	11	3	132	10[7]	89	57%
Chlorophyll *a* (ug/l) – Lab Determined	1	24	37	34	0.00	132	10[7]	18	75%
Hardness, Total (mg/l)	0.4	5	151.4	153.0	127.0	176.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.10	50	1.8	1.7	0.6	5.9	-----	-----	-----
Nitrogen, Total (mg/)	0.10	50	1.9	1.8	0.6	5.9	1[7]	48	96%
Nitrate-Nitrite N, Total (mg/l)	0.02	50	-----	n.d.	n.d.	0.80	100[3]	0	0%
Phosphorus, Total (mg/l)	0.02	50	0.19	0.14	n.d.	0.60	0.05[7]	49	98%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	-----	0.04	n.d.	0.53	-----	-----	-----
Suspended Solids, Total (mg/l)	4	50	23	20	6	62	-----	-----	-----
Aluminum, Dissolved (ug/l)	25	5	-----	n.d.	n.d.	70	750[5], 87[6]	0	0%
Antimony, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	88[5], 30[6]	0	0%
Arsenic, Dissolved (ug/l)	3	5	6	6	4	9	340[5], 16.7[8]	0	0%
Beryllium, Dissolved (ug/l)	3	5	-----	n.d.	n.d.	n.d.	130[5], 5.3[6]	0	0%
Cadmium, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	8.9[5], 0.3[6]	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	3	838[5], 109[6]	0	0%
Copper, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	2	20[5], 13[6]	0	0%
Lead, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	102[5], 4[6]	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4[5]	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77[6]	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	671[5], 74.5[6]	0	0%
Selenium, Total (ug/l)	2	5	-----	n.d.	n.d.	7	20[3,5], 5[6]	0, 1	0%, 20%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	6.5[5]	0	0%
Thallium (ug/l)	6	5	-----	n.d.	n.d.	n.d.	1,400[5], 6.3[8]	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	168[5,6]	0	0%
Microcystin, Total (ug/l)	0.05	24	-----	n.d.	n.d.	1.25	20[9]	0	0%
Acetochlor, Total (ug/l)[C]	0.05	15	0.59	0.30	n.d.	2.10	-----	-----	-----
Alachlor, Total (ug/l)[C]	0.05	9	0.24	0.20	n.d.	0.50	760[5], 76[6]	0	0%
Atrazine, Total (ug/l)[C]	0.05	24	1.54	1.30	n.d.	4.40	330[5], 12[6]	0	0%
Metolachlor, Total (ug/l)[C]	0.05	24	-----	0.15	n.d.	2.40	390[5], 100[6]	0	0%
Pesticide Scan (ug/l)[D]	0.05						-----	-----	-----
Atrazine		5	-----	0.70	n.d.	1.10	330[5], 12[6]	0	0%
Dethylatrazine		4	-----	n.d.	n.d.	0.30	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.

(2) Use-specific criteria for aquatic life.

(3) Agricultural criteria for surface waters.

(4) Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.

(5) Acute criteria for aquatic life.

(6) Chronic criteria for aquatic life.

(7) Nutrient criteria for aquatic life.

(8) Human health criteria.

(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l microcystins in recreation water for impairment assessment.

Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 111. Summary of water quality conditions monitored in Conestoga Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site CONLKML1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	24	1231.4	1232.7	1225.8	1234.1	-----	-----	-----
Water Temperature (°C)	0.1	152	23.8	24.7	15.6	33.5	32(1)	1	1%
Dissolved Oxygen (mg/l)	0.1	152	7.9	7.6	0.7	12.5	≥ 5(2)	11	7%
Dissolved Oxygen (% Sat.)	0.1	143	95.6	90.6	8.5	171.2	-----	-----	-----
Specific Conductance (umho/cm)	1	143	443	419	324	637	2,000(3)	0	0%
pH (S.U.)	0.1	143	8.2	8.2	7.3	9.3	≥6.5 & ≤9.0(1)	1	1%
Turbidity (NTUs)	1	143	39	26	8	145	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	143	318	329	130	451	-----	-----	-----
Secchi Depth (in.)	1	25	17	17	1	32	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	113	29	12	3	193	10(4)	75	66%

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

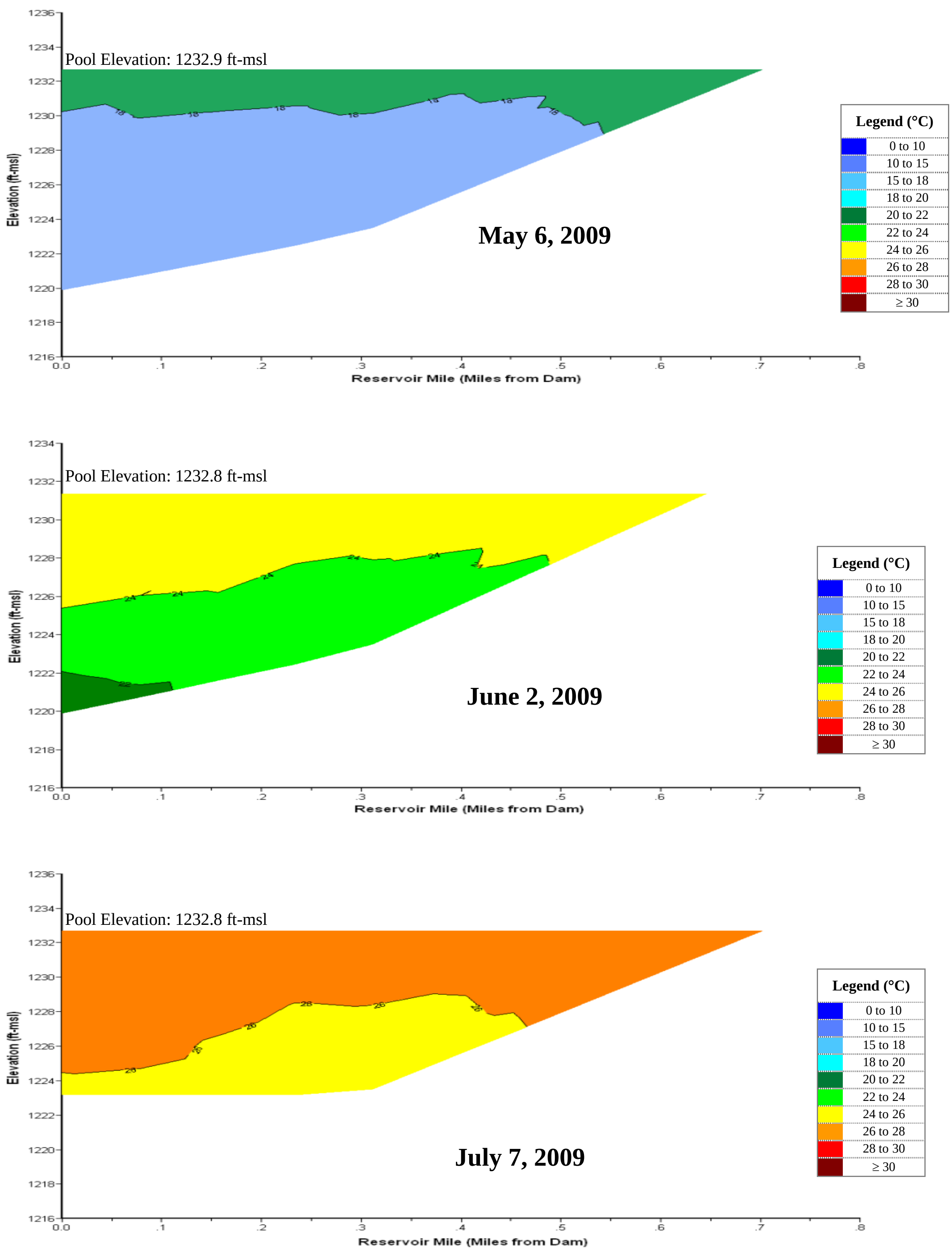
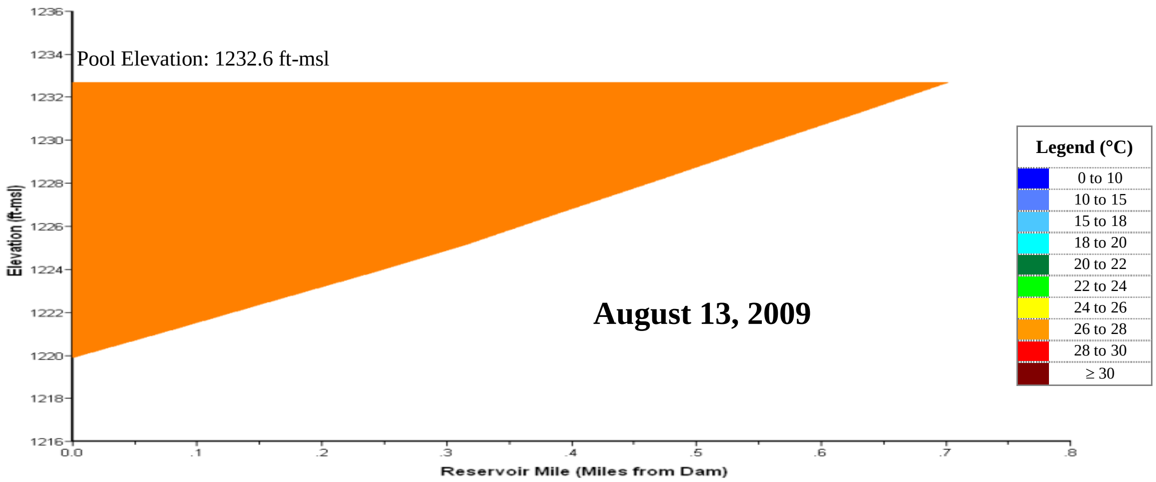


Plate 112. Longitudinal water temperature (°C) contour plots of Conestoga Reservoir based on depth-profile water temperatures measured at sites CONLKND1 and CONLKML1 in 2009.



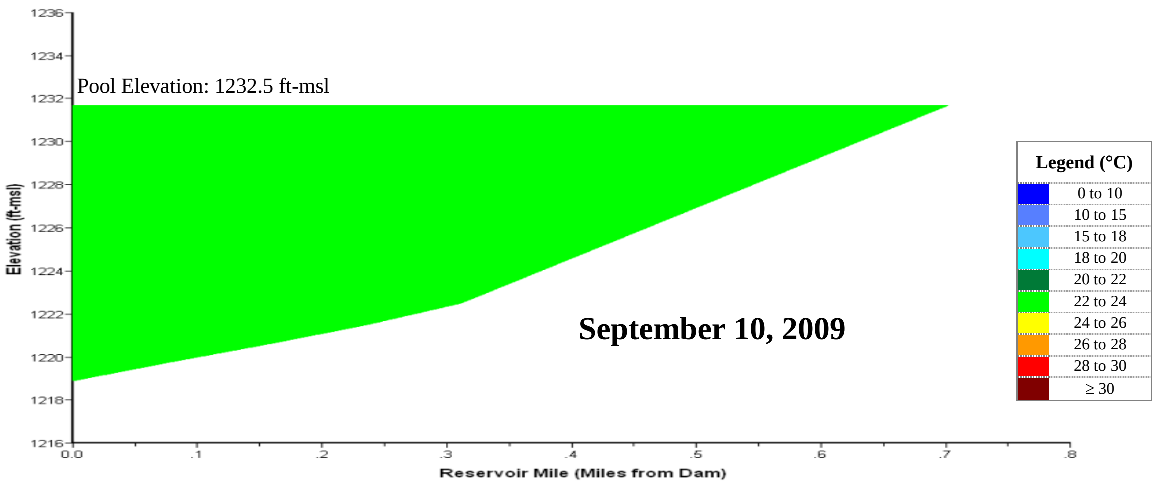


Plate 112. (Continued).

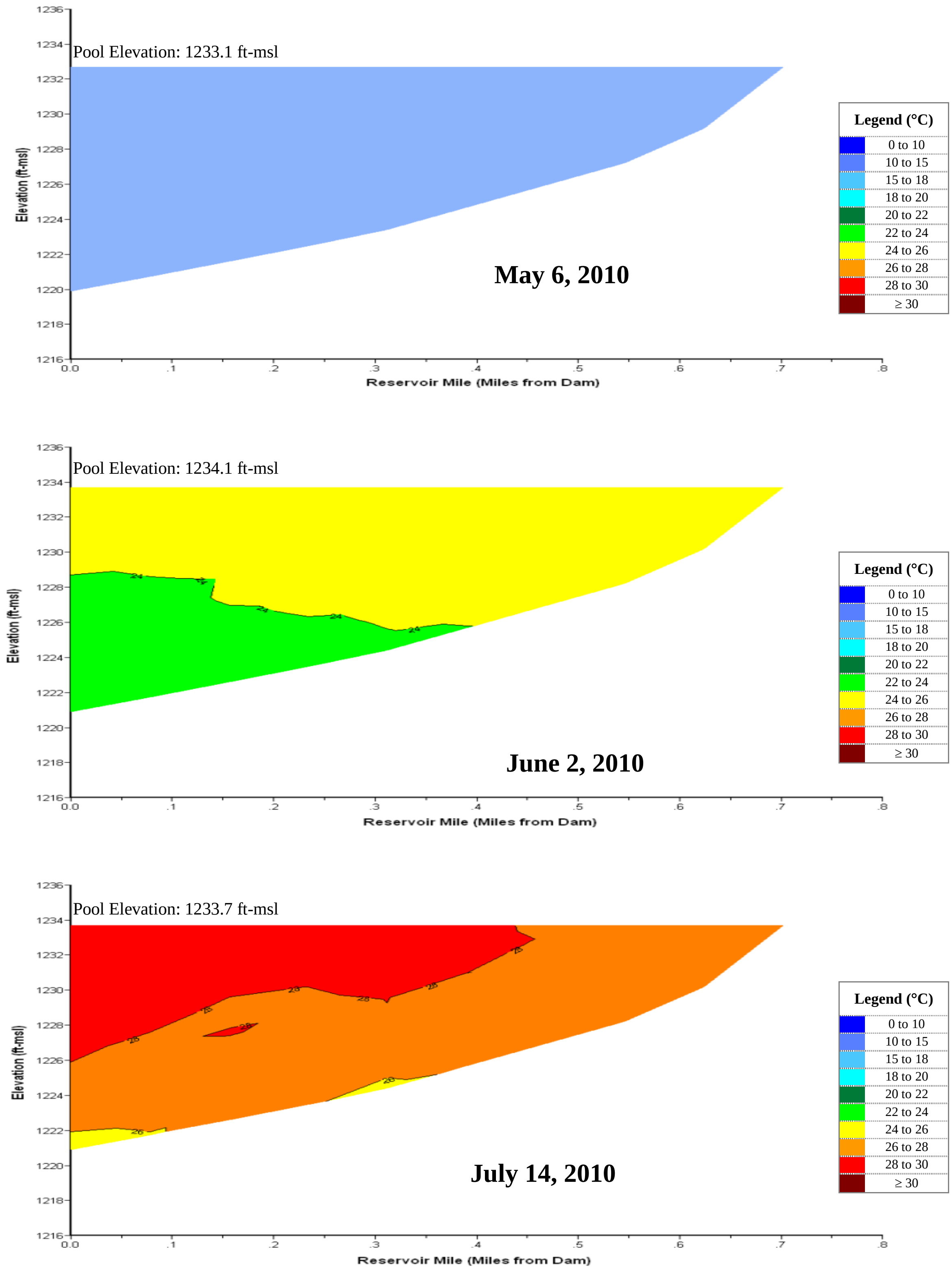
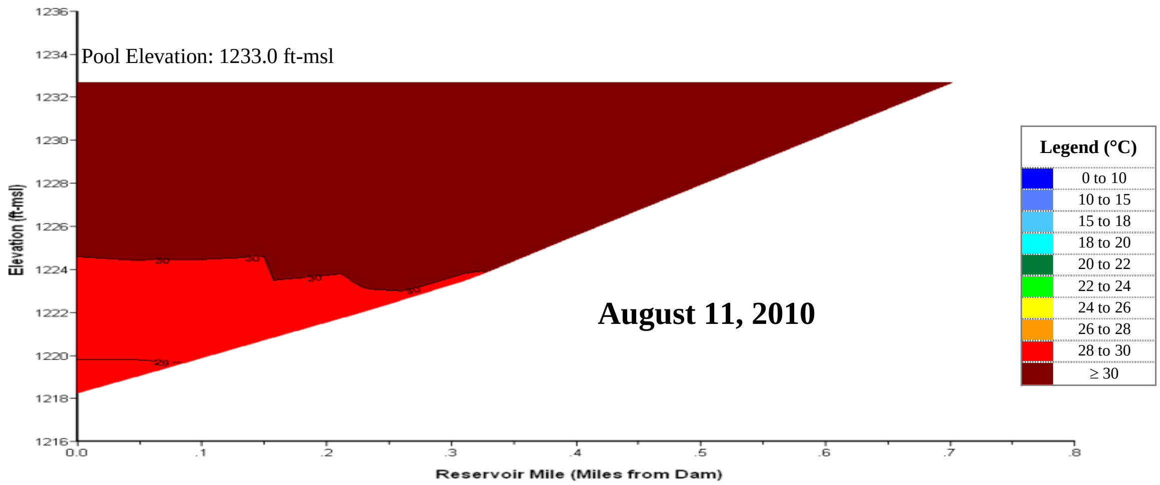


Plate 113. Longitudinal water temperature (°C) contour plots of Conestoga Reservoir based on depth-profile water temperatures measured at sites CONLKND1, CONLKML1, and CONLKUP1 in 2010.



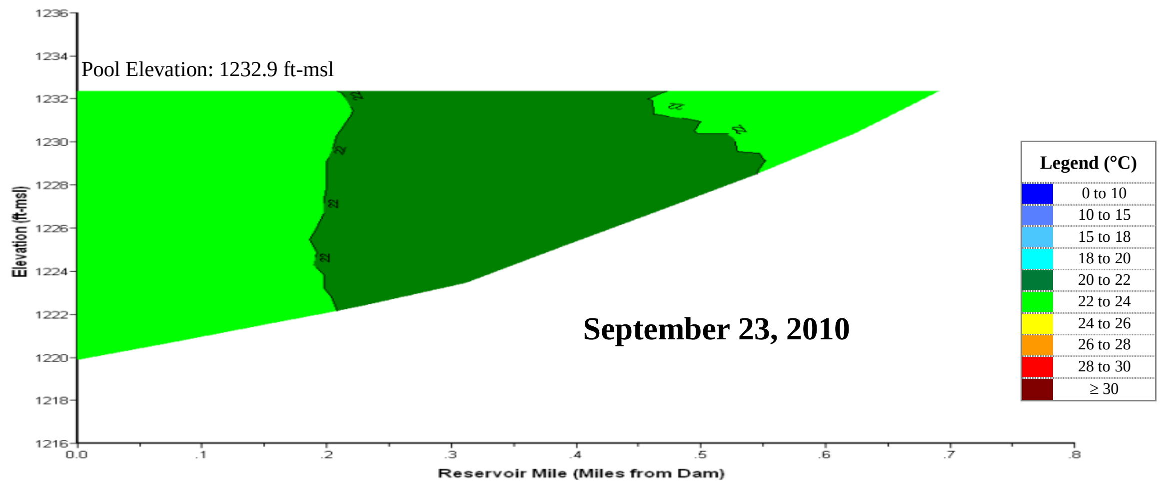


Plate 113. (Continued).

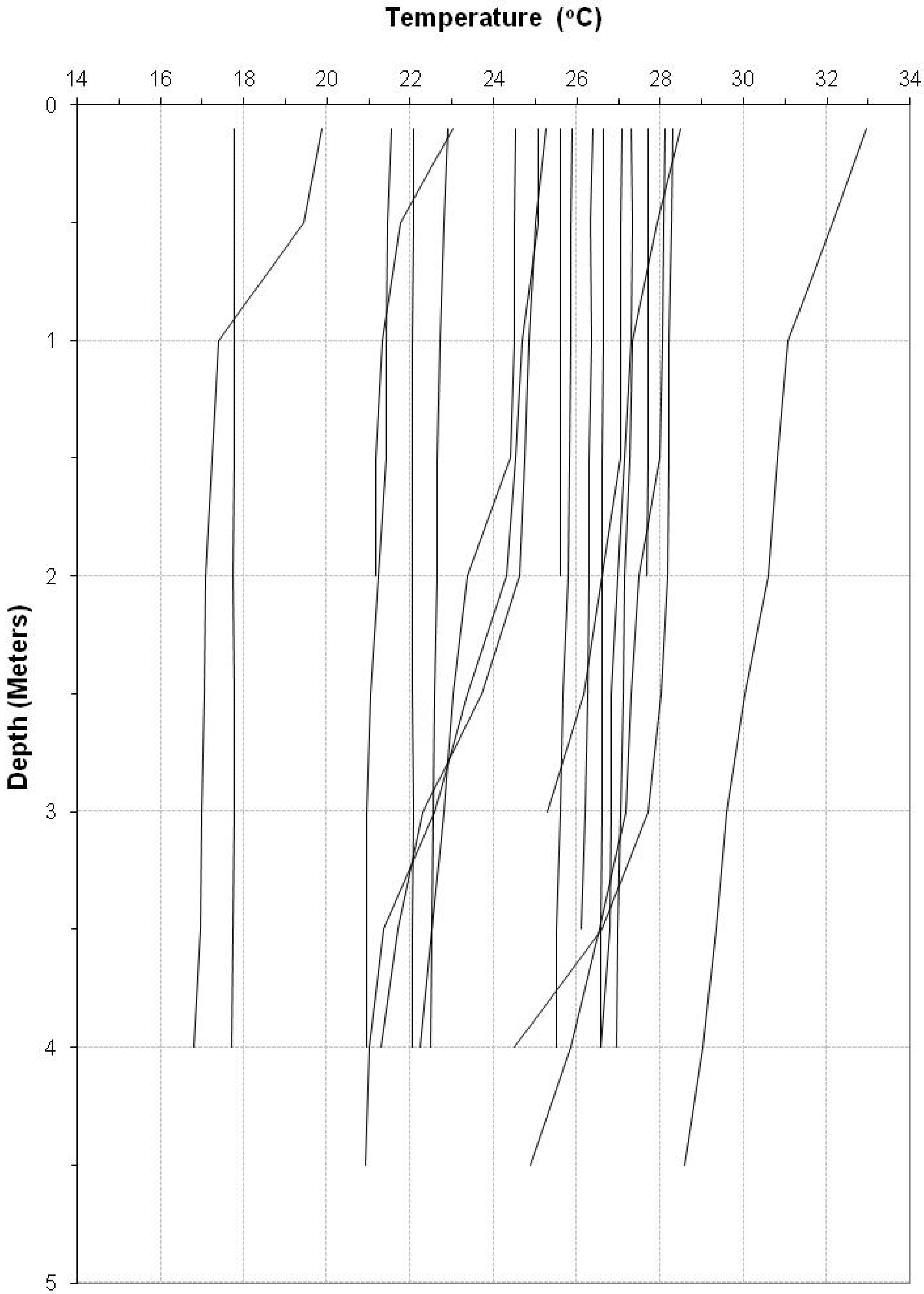


Plate 114. Temperature depth profiles for Conestoga Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., CONLKND1) during the summer over the 5-year period of 2006 through 2010.

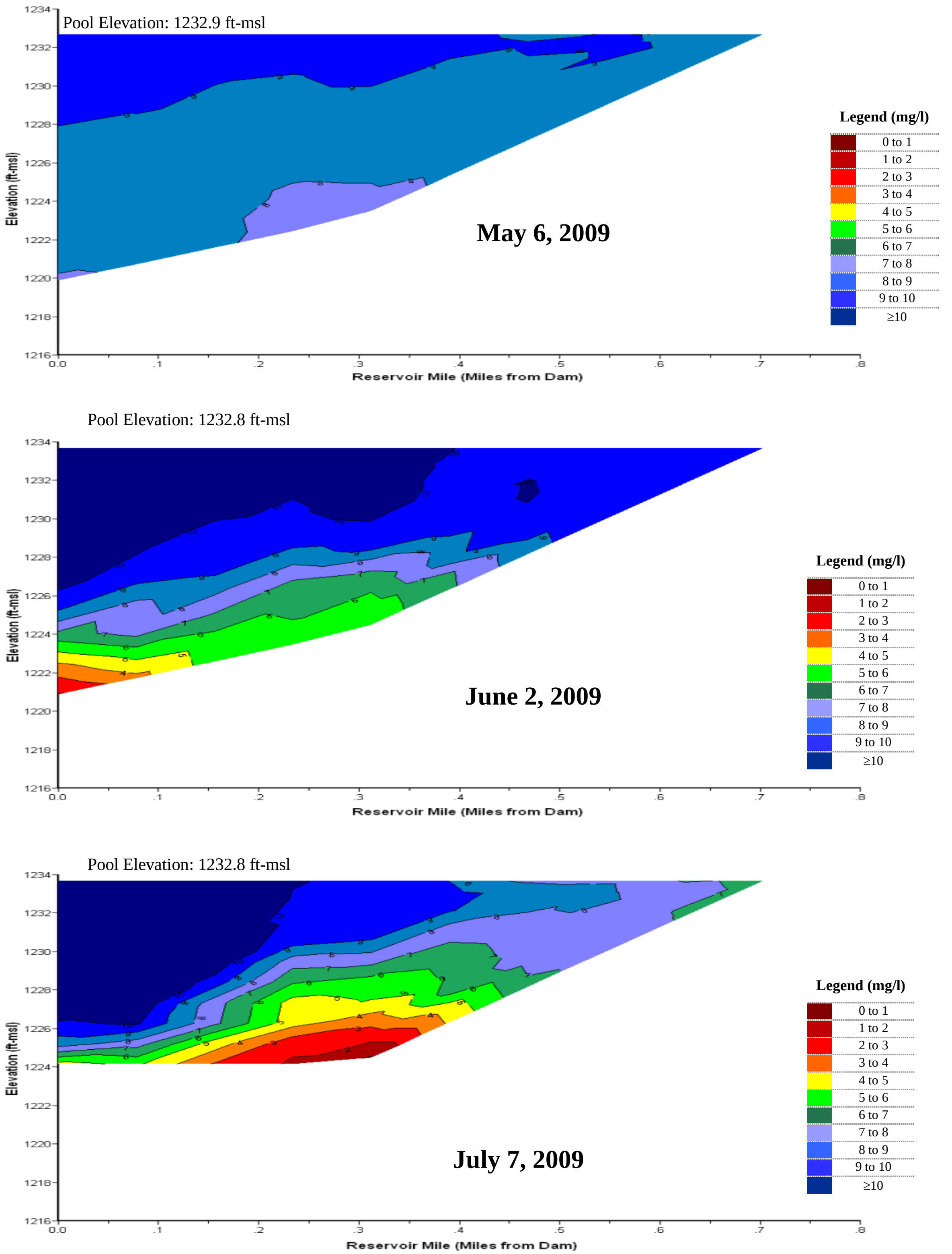
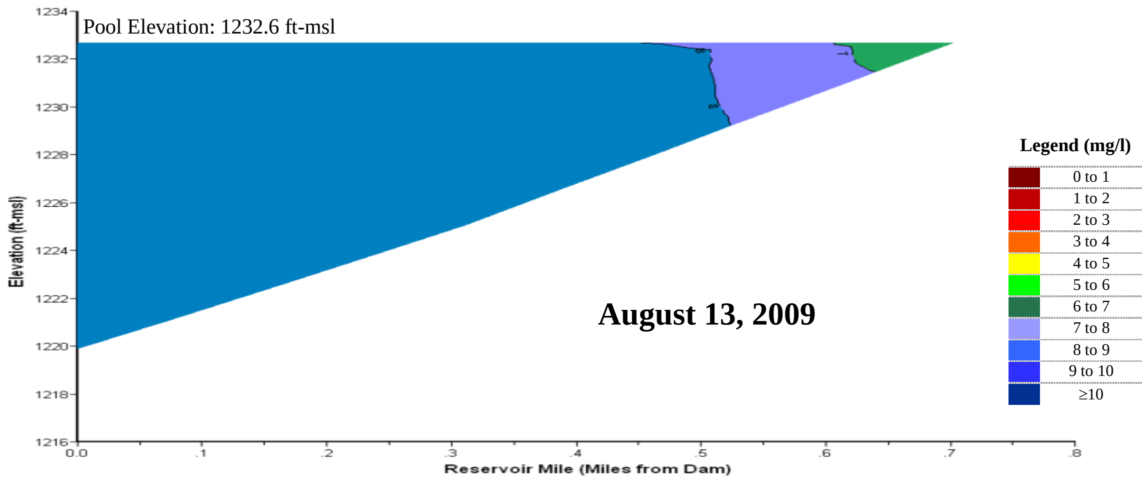


Plate 115. Longitudinal dissolved oxygen (mg/l) contour plots of Conestoga Reservoir based on depth-profile dissolved oxygen concentrations measured at sites CONLKND1 and CONLKML1 in 2009.



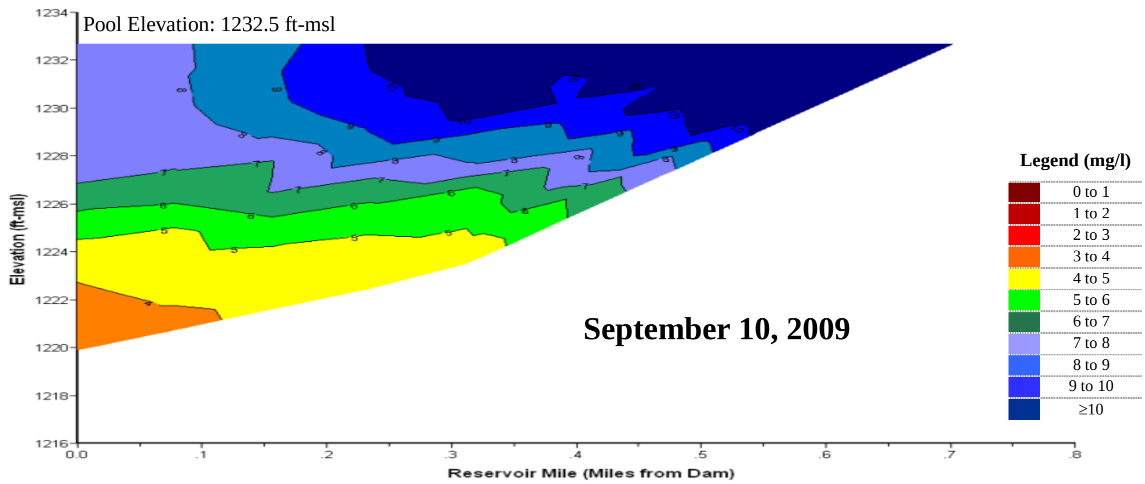


Plate 115. (Continued).

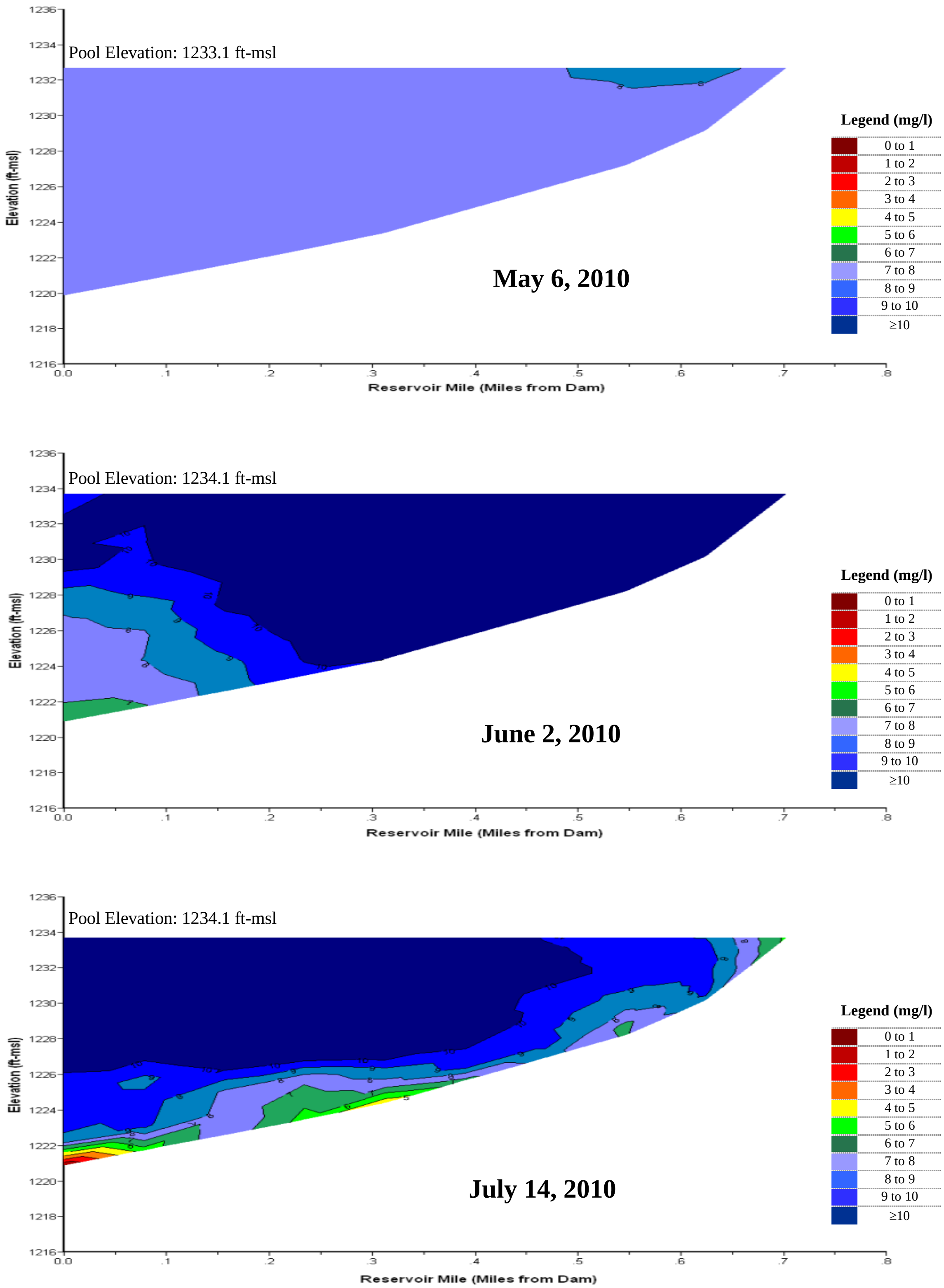
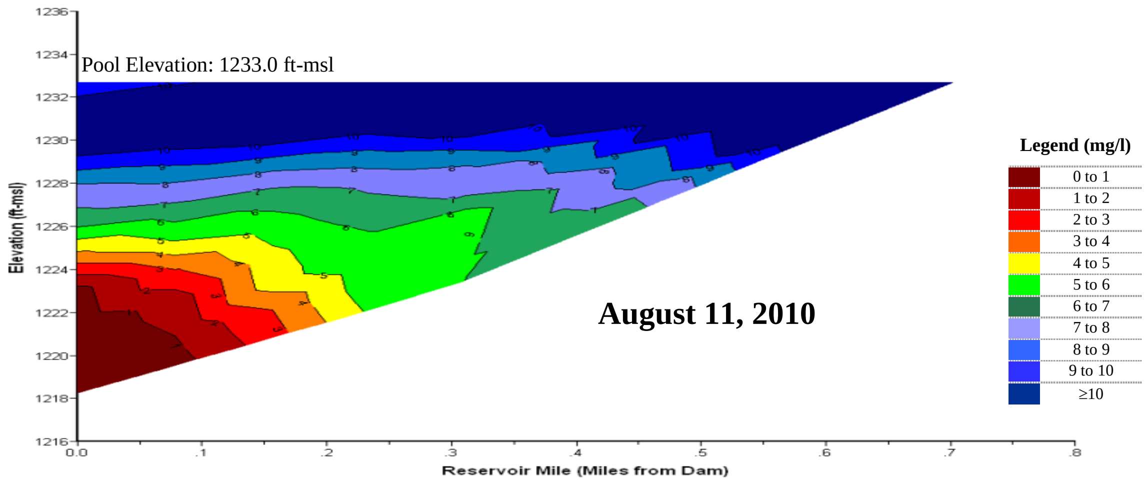


Plate 116. Longitudinal dissolved oxygen (mg/l) contour plots of Conestoga Reservoir based on depth-profile dissolved oxygen concentrations measured at sites CONLKND1, CONLKML1, and CONLKUP1 in 2010.



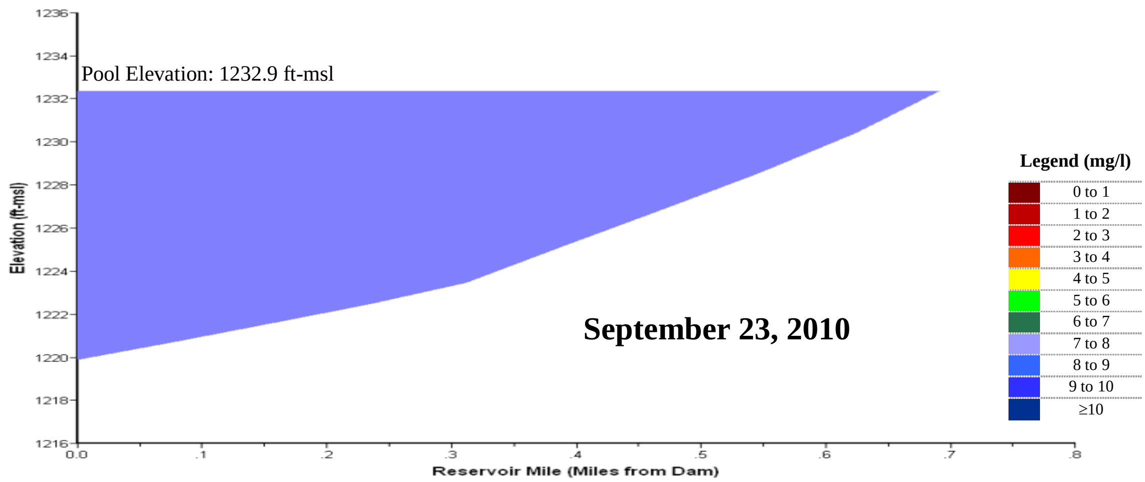


Plate 116. (Continued).

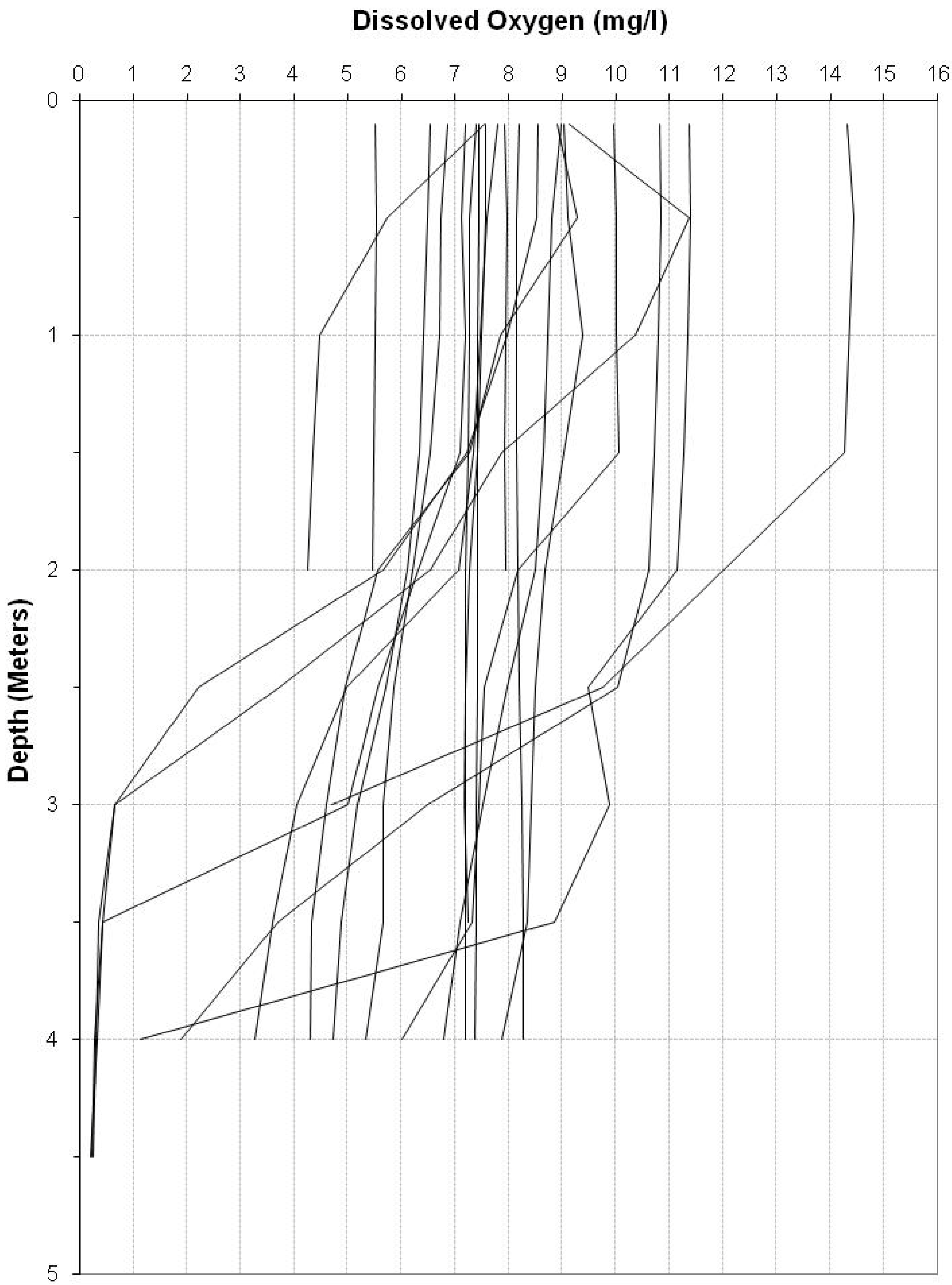


Plate 117. Dissolved oxygen depth profiles for Conestoga Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., CONLKND1) during the summer over the 5-year period of 2006 through 2010.

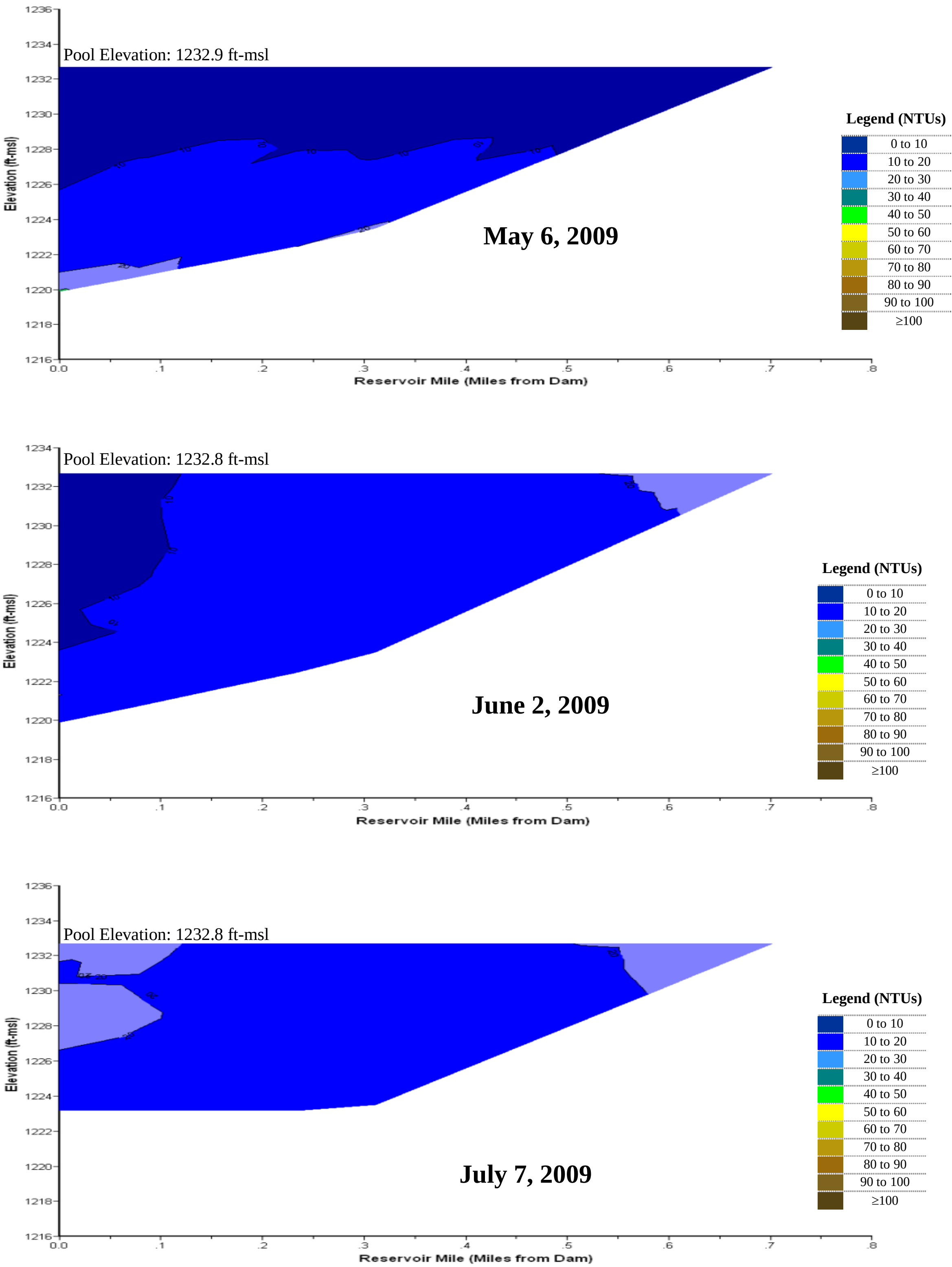
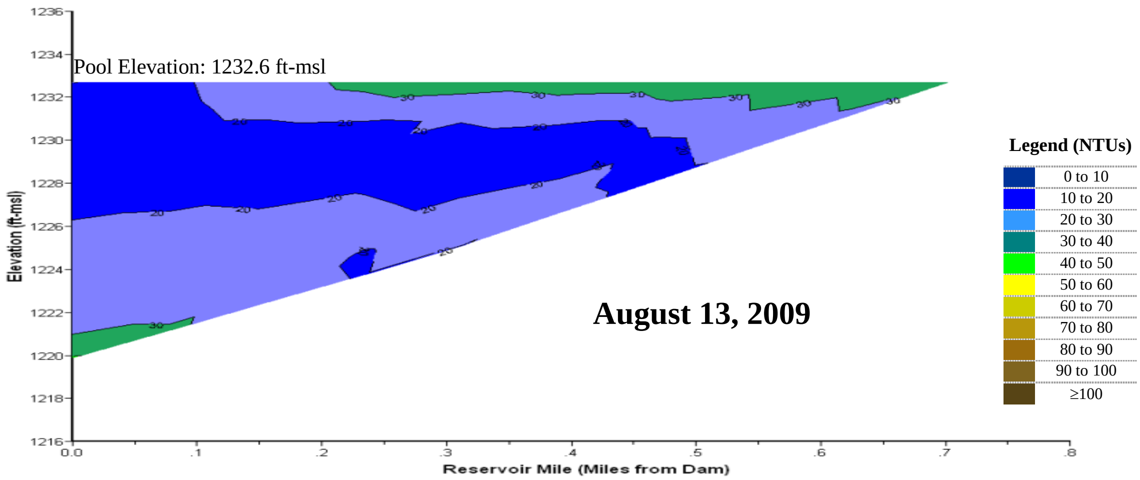


Plate 118. Longitudinal turbidity (NTU) contour plots of Conestoga Reservoir based on depth-profile turbidity levels measured at sites CONLKND1 and CONLKML1 in 2009.



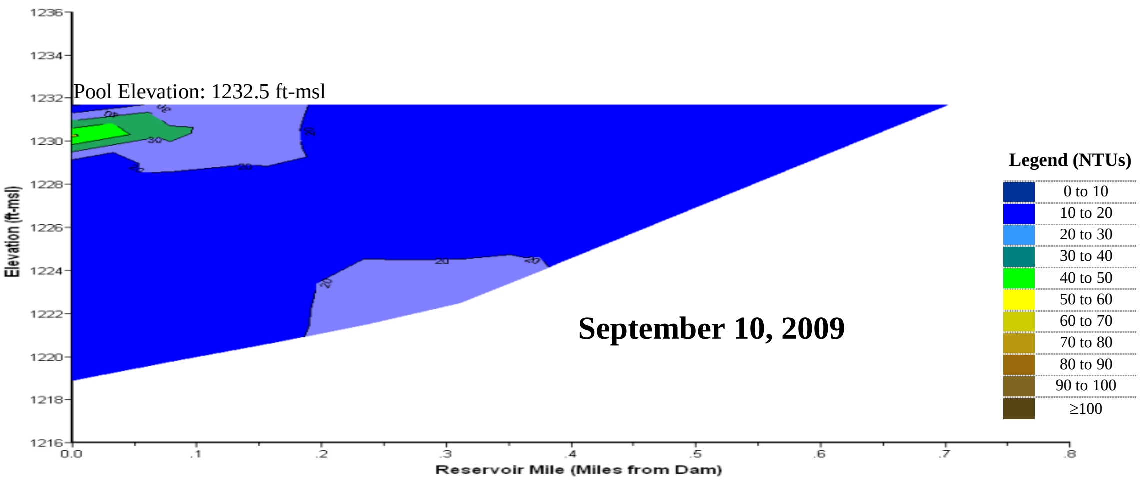


Plate 118. (Continued).

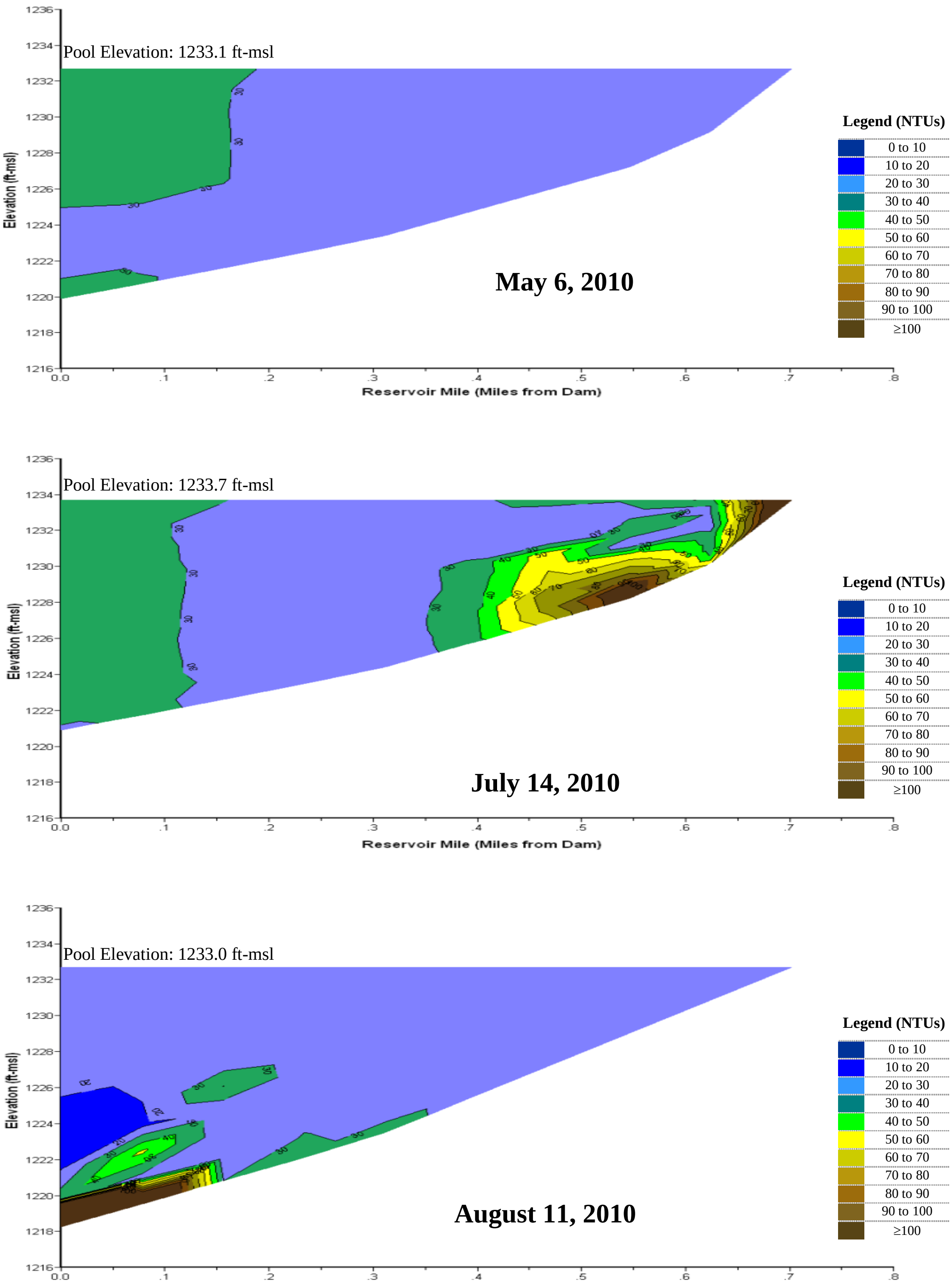


Plate 119. Longitudinal turbidity (NTU) contour plots of Conestoga Reservoir based on depth-profile turbidity levels measured at sites CONLKND1, CONLKML1, and CONLKUP1 in 2010.

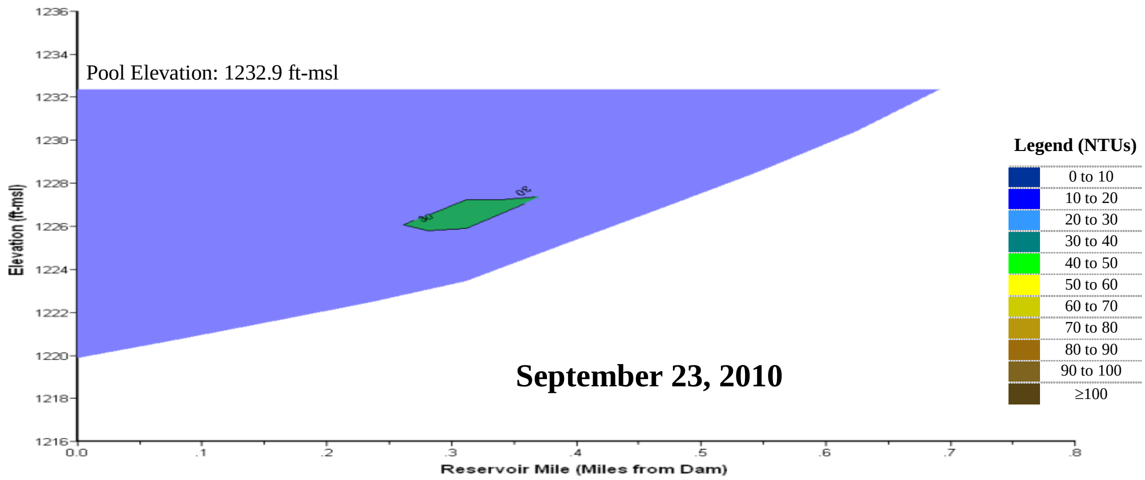


Plate 119. (Continued).

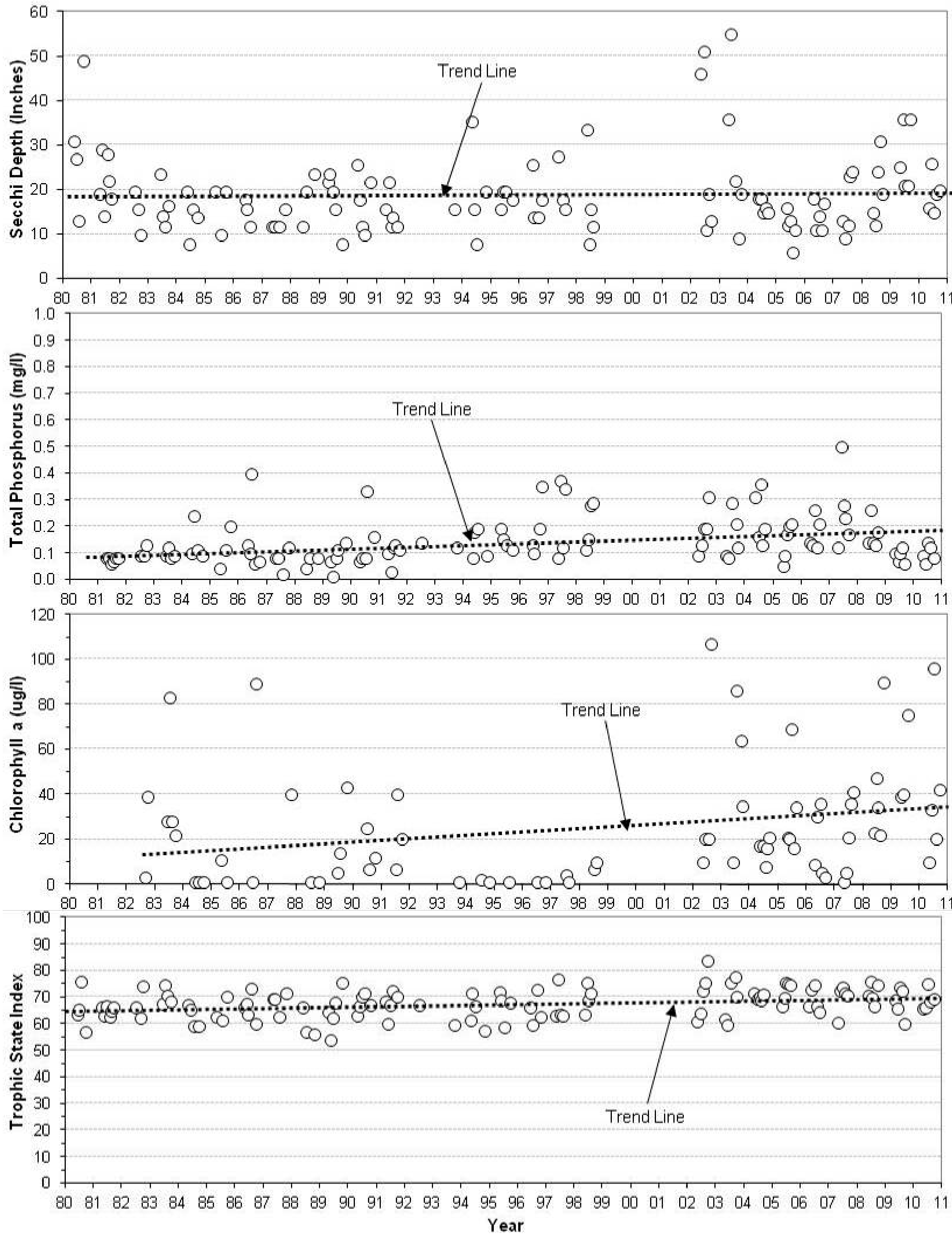


Plate 120. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Conestoga Reservoir at the near-dam, ambient site (i.e., site CONLKND1) over the 31-year period of 1980 through 2010.

Plate 121. Summary of runoff water quality conditions monitored in the main tributary inflow to Conestoga Reservoir at monitoring site CONNF1 during the 5-year period 2004 through 2008. Runoff conditions have not been monitored since 2008.

	Monitoring Results						Water Quality Standards Attainment		
Parameter	**Detection Limit**	**No. of Obs.**	**Mean[A]**	**Median**	**Min.**	**Max.**	**State WQS Criteria[B]**	**No. of WQS Exceedences**	**Percent WQS Exceedence**
Kjeldahl N, Total (mg/l)	0.1	5	4.2	4.5	2.78	6.0	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	5	1.45	1.53	0.92	2.04		-----	-----
Phosphorus, Total (mg/l)	0.02	5	1.34	1.60	0.85	1.69	-----	-----	-----
Suspended Solids, Total (mg/l)	4	5	746	730	256	1,270	-----	-----	-----
Acetochlor, Total (ug/l)[C]	0.05	3	1.49	0.73	0.56	3.19	-----	-----	-----
Atrazine, Total (ug/l)[C]	0.05	4	24.17	9.20	2.28	76.00	330[1], 12[2]	0, 2	0%, 50%
Metolachlor, Total (ug/l)[C]	0.05	3	-----	1.76	n.d.	9.02	390[1], 100[2]	0	0%

n.d. = Not detected.

[A] Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.

[B] [1] Acute criterion for aquatic life.

[2] Chronic criterion for aquatic life.

[C] Immunoassay analysis.

Plate 122. Summary of water quality conditions monitored in Holmes Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site HOLLKND1) from May to September during the 3-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface Secchi depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	25	1242.3	1242.4	1240.4	1244.6	-----	-----	-----
Water Temperature (°C)	0.1	195	23.2	24.1	14.4	29.7	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	195	7.7	8.2	0.3	17.1	≥ 5[2]	37	19%
Dissolved Oxygen (% Sat.)	0.1	188	94.3	92.2	3.2	235.5	-----	-----	-----
Specific Conductance (umho/cm)	1	195	388	355	240	694	2,000[3]	0	0%
pH (S.U.)	0.1	195	8.5	8.6	6.5	9.8	≥6.5 & ≤9.0[1]	36	18%*
Turbidity (NTUs)	1	195	15	13	1	51	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	195	297	299	-30	469	-----	-----	-----
Secchi Depth (in.)	1	24	42	30	16	108	-----	-----	-----
Alkalinity, Total (mg/l)	7	52	125	119	87	196	20[1]	0	0%
Ammonia, Total (mg/l)	0.02	52	-----	0.03	0.00	0.71	2.64[4,5], 0.49[4,6]	0, 3	0%, 6%
Chlorophyll *a* (ug/l) – Field Probe	1	153	31	14	2	164	10[7]	95	62%
Chlorophyll *a* (ug/l) – Lab Determined	1	26	36	28	3	131	10[7]	19	73%
Hardness, Total (mg/l)	0.4	5	96.2	100.0	70.0	113.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.10	52	1.3	1.3	0.5	2.1	-----	-----	-----
Nitrogen, Total (mg/)	0.10	52	1.3	1.3	0.5	2.1	1[7]	22	69%
Nitrate-Nitrite N, Total (mg/l)	0.02	52	-----	n.d.	n.d.	0.09	100[3]	0	0%
Phosphorus, Total (mg/l)	0.10	52	0.1	0.1	n.d.	0.5	0.05[7]	49	94%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	52	-----	0.03	n.d.	0.30	-----	-----	-----
Suspended Solids, Total (mg/l)	4	50	10	9	n.d.	28	-----	-----	-----
Aluminum, Dissolved (ug/l)	25	5	-----	n.d.	n.d.	32	750[5], 87[6]	0	0%
Antimony, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	1	88[5], 30[6]	0	0%
Arsenic, Dissolved (ug/l)	3	5	8	9	4	10	340[5], 16.7[8]	0	0%
Beryllium, Dissolved (ug/l)	3	5	-----	n.d.	n.d.	n.d.	130[5], 5.3[6]	0	0%
Cadmium, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	6.6[5], 0.3[6]	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	650[5], 85[6]	0	0%
Copper, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	15[5], 9.9[6]	0	0%
Lead, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	73[5], 2.9[6]	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4[5]	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77[6]	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	515[5], 57[6]		
Selenium, Total (ug/l)	2	5	-----	n.d.	n.d.	10	20[3,5], 5[6]	0, 1	0, 20%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	4.2[5]	0	0%
Thallium (ug/l)	3	5	-----	n.d.	n.d.	n.d.	1,400[5], 6.3[8]	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	129[5,6]	0	0%
Microcystin, Total (ug/l)	0.05	26	-----	0.12	n.d.	1.90	20[9]	0	0%
Acetochlor, Total (ug/l)[C]	0.05	15	-----	0.10	n.d.	0.30	-----	-----	-----
Alachlor, Total (ug/l)[C]	0.05	11	-----	n.d.	n.d.	0.05	760[5], 76[6]	0	0%
Atrazine, Total (ug/l)[C]	0.05	26	0.23	0.22	n.d.	0.59	330[5], 12[6]	0	0%
Metolachlor, Total (ug/l)[C]	0.05	26	-----	n.d.	n.d.	0.40	390[5], 100[6]	0	0%
Pesticide Scan (ug/l)[D]	0.05						330[5], 12[6]	0	0%
Atrazine		5	-----	n.d.	n.d.	1.70	330[5], 12[6]	0	0%
Oxyfluorfen		1	0.86	0.86	0.86	0.86	-----	-----	-----

n.d. = Not detected.

[A] Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

[B] [1] General criteria for aquatic life.
[2] Use-specific criteria for aquatic life.
[3] Agricultural criteria for surface waters.
[4] Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
[5] Acute criteria for aquatic life.
[6] Chronic criteria for aquatic life.
[7] Nutrient criteria for aquatic life.
[8] Human health criteria.
[9] Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l microcystins in recreation water for impairment assessment.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

[C] Immunoassay analysis.

[D] The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 123. Summary of water quality conditions monitored in Holmes Reservoir at the mid-lake, deepwater ambient monitoring location in the north arm (i.e., site HOLLKMLN1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, and ORP are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	23	1242.3	1242.3	1240.4	1244.6	-----	-----	-----
Water Temperature (°C)	0.1	170	23.3	24.4	13.7	29.7	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	170	7.8	8.4	0.3	16.6	≥ 5(2)	27	16%
Dissolved Oxygen (% Sat.)	0.1	164	95.3	91.8	3.7	217.6	-----	-----	-----
Specific Conductance (umho/cm)	1	170	385	351	230	639	2,000(3)	0	0%
pH (S.U.)	0.1	170	8.6	8.7	6.7	9.5	≥6.5 & ≤9.0(1)	33	19%*
Turbidity (NTUs)	1	170	13	12	1	90	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	170	314	312	-37	500	-----	-----	-----
Secchi Depth (in.)	1	24	42	30	19	120	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	135	26	12	2	141	10(4)	80	59%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).
(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 124. Summary of water quality conditions monitored in Holmes Reservoir at the mid-lake, deepwater ambient monitoring location in the south arm (i.e., site HOLLKMLS1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, and ORP are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	23	1242.4	1242.4	1240.4	1244.6	-----	-----	-----
Water Temperature (°C)	0.1	169	23.3	24.3	14.3	29.3	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	168	7.4	8.1	0.3	17.4	≥ 5(2)	43	26%
Dissolved Oxygen (% Sat.)	0.1	162	90.4	95.4	4.0	226.5	-----	-----	-----
Specific Conductance (umho/cm)	1	169	379	333	191	624	2,000(3)	0	0%
pH (S.U.)	0.1	169	8.5	8.5	6.9	9.8	≥6.5 & ≤9.0(1)	34	20%*
Turbidity (NTUs)	1	162	13	11	1	45	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	169	317	317	-6	528	-----	-----	-----
Secchi Depth (in.)	1	24	38	30	15	82	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	134	29	15	3	150	10(4)	87	65%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).
(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

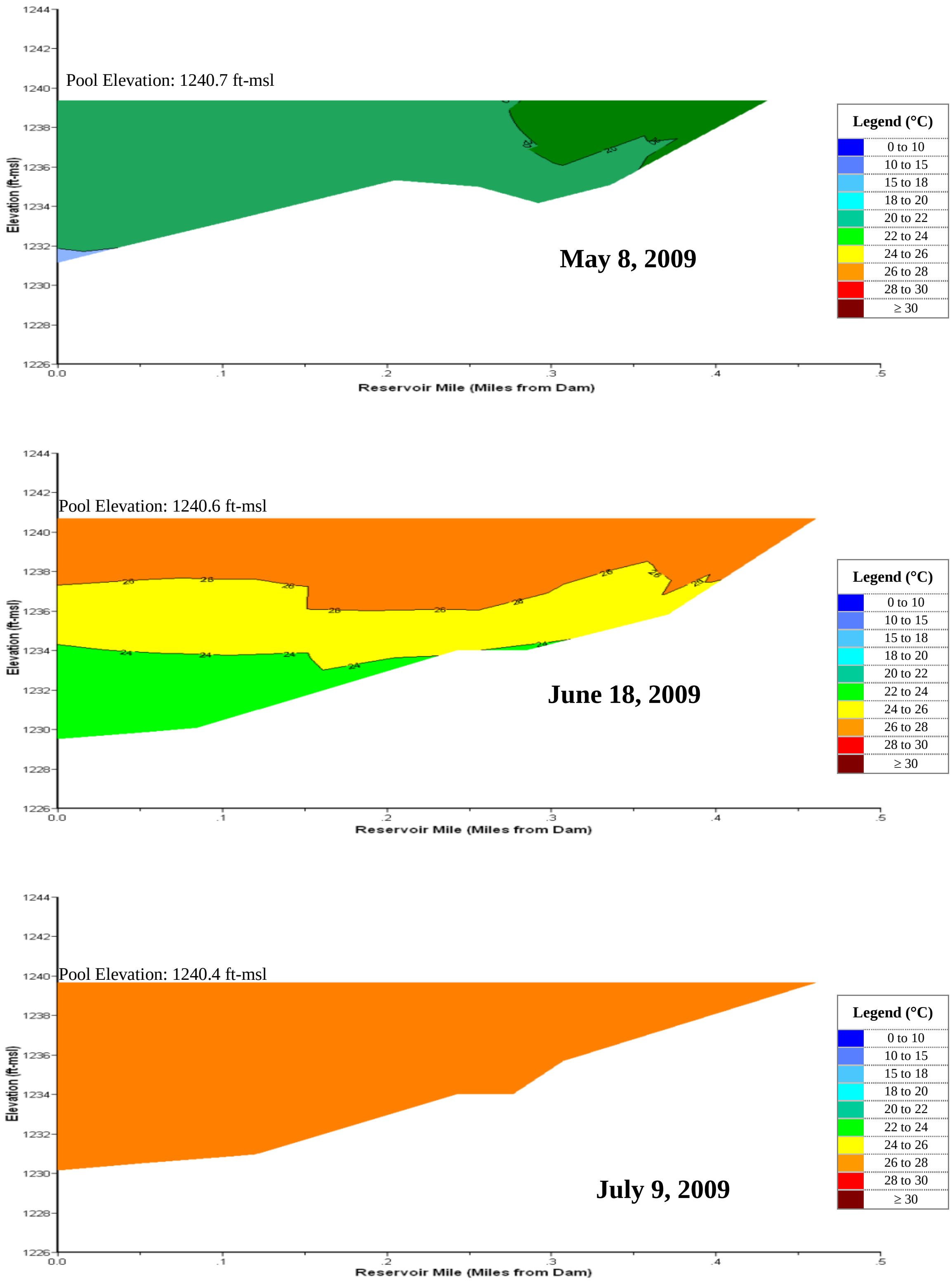
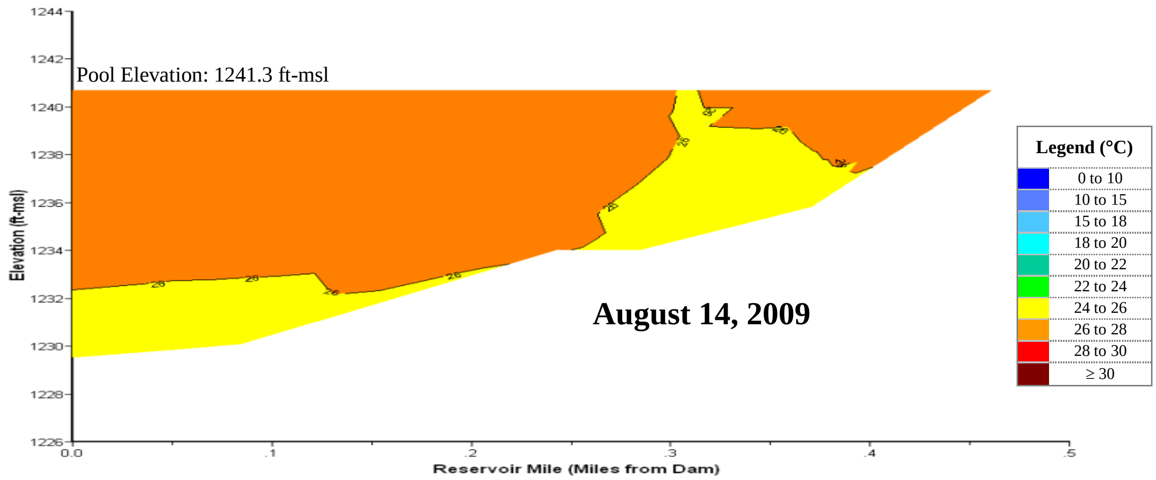


Plate 125. Longitudinal water temperature (°C) contour plots of Holmes Reservoir through the north arm based on depth-profile water temperatures measured at sites HOLLKND1 and HOLLKMLN1 in 2009.



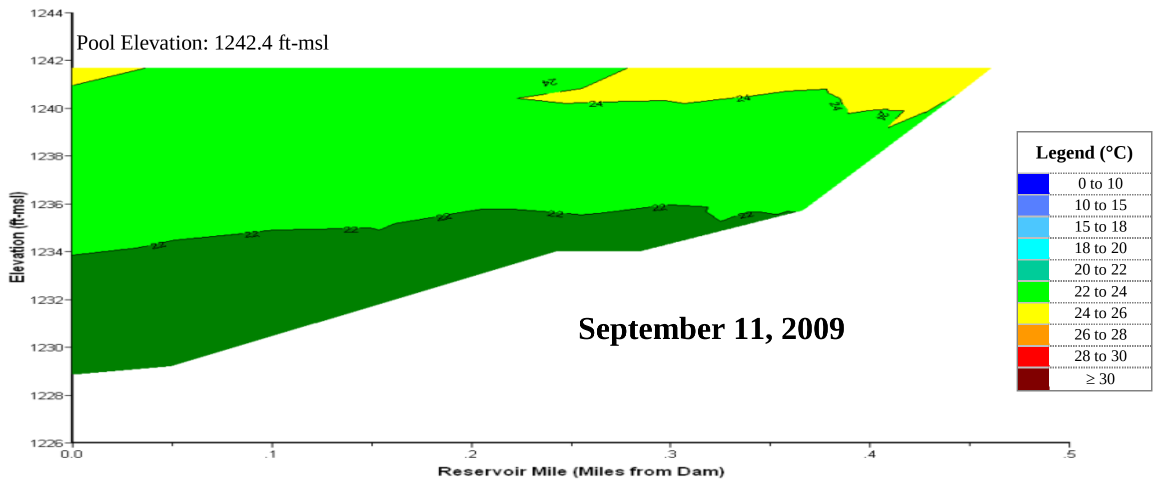
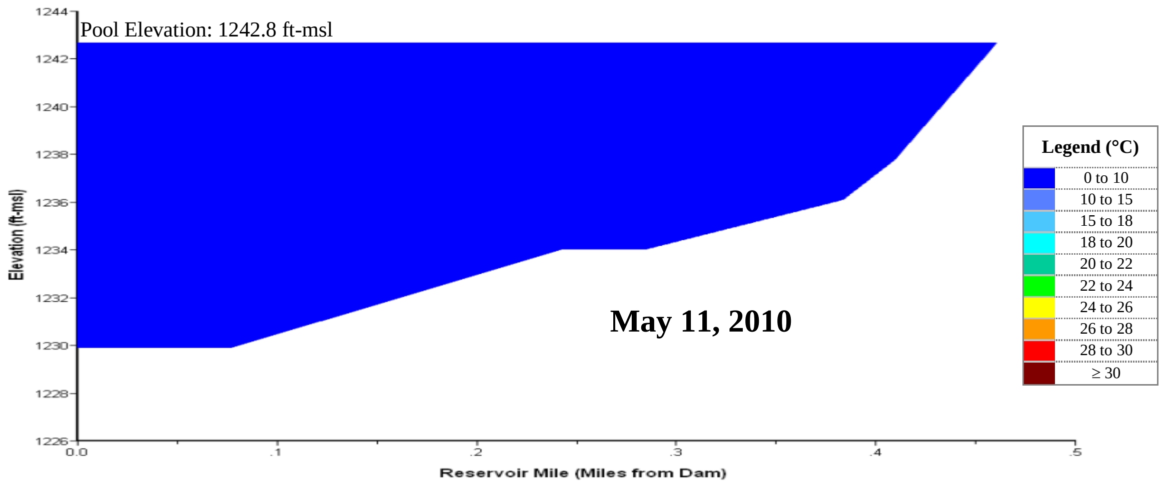
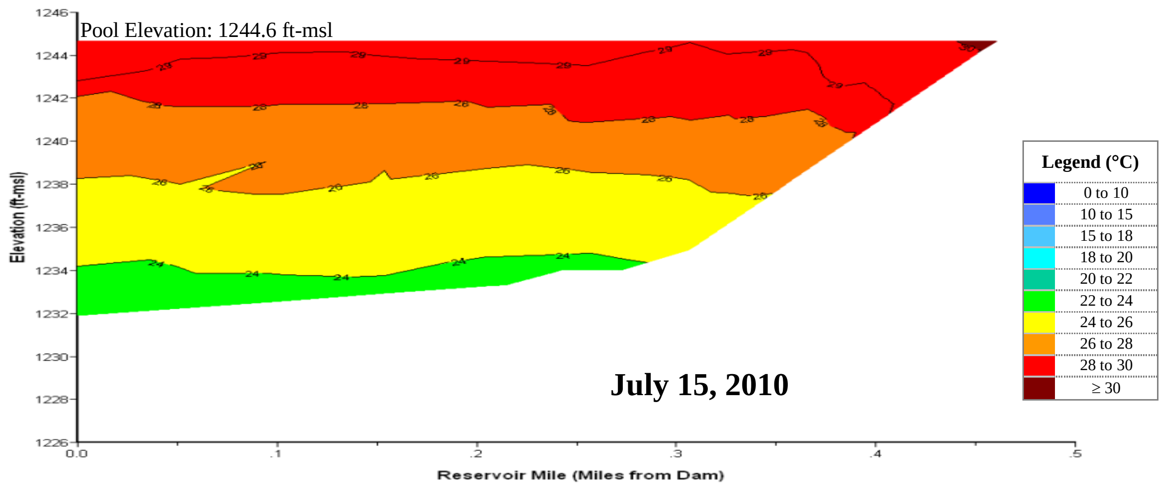


Plate 125. (Continued).





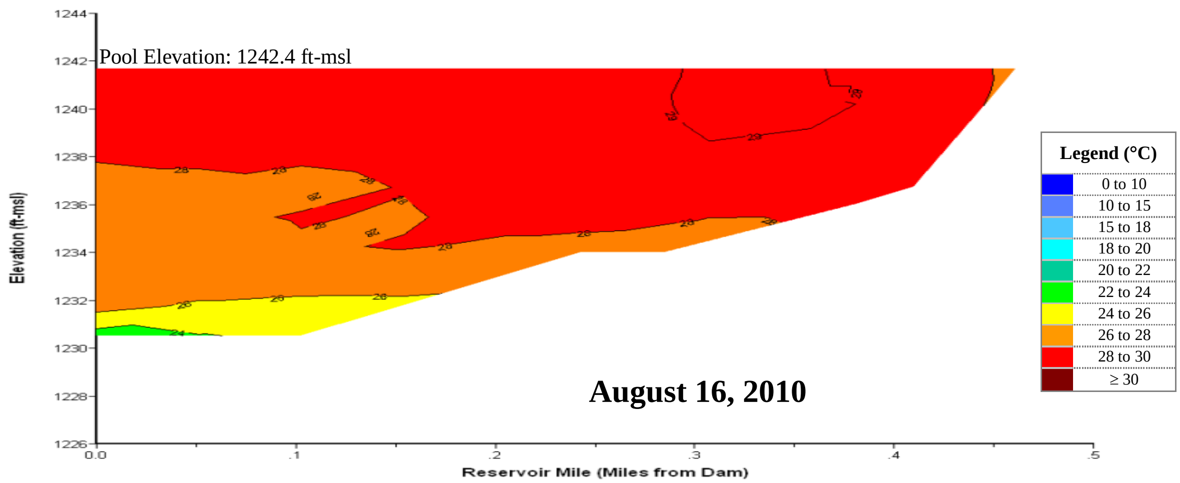


Plate 126. Longitudinal water temperature (°C) contour plots of Holmes Reservoir through the north arm based on depth-profile water temperatures measured at sites HOLLKND1, HOLLKMLN1, and HOLLKUP1 in 2010.

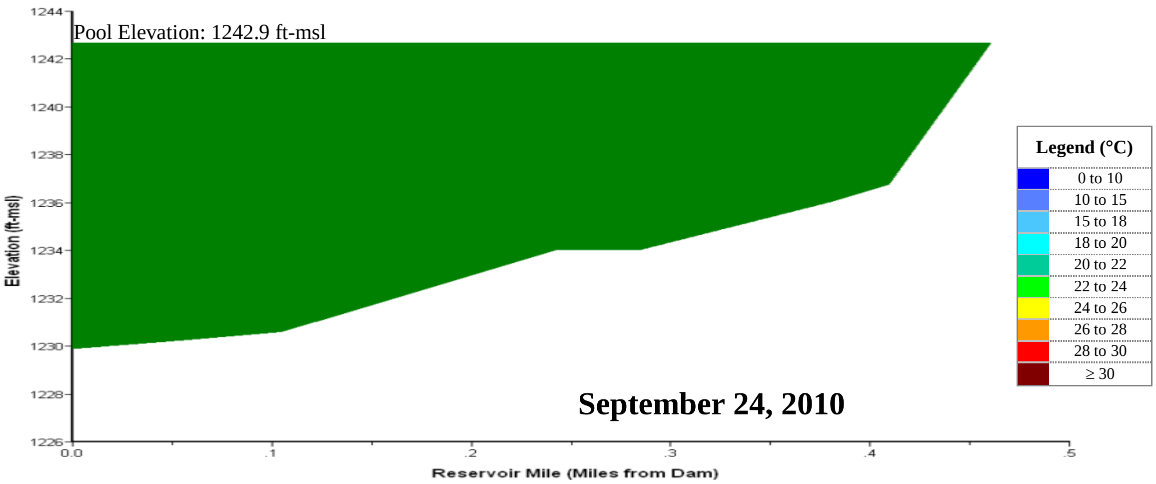


Plate 126. (Continued).

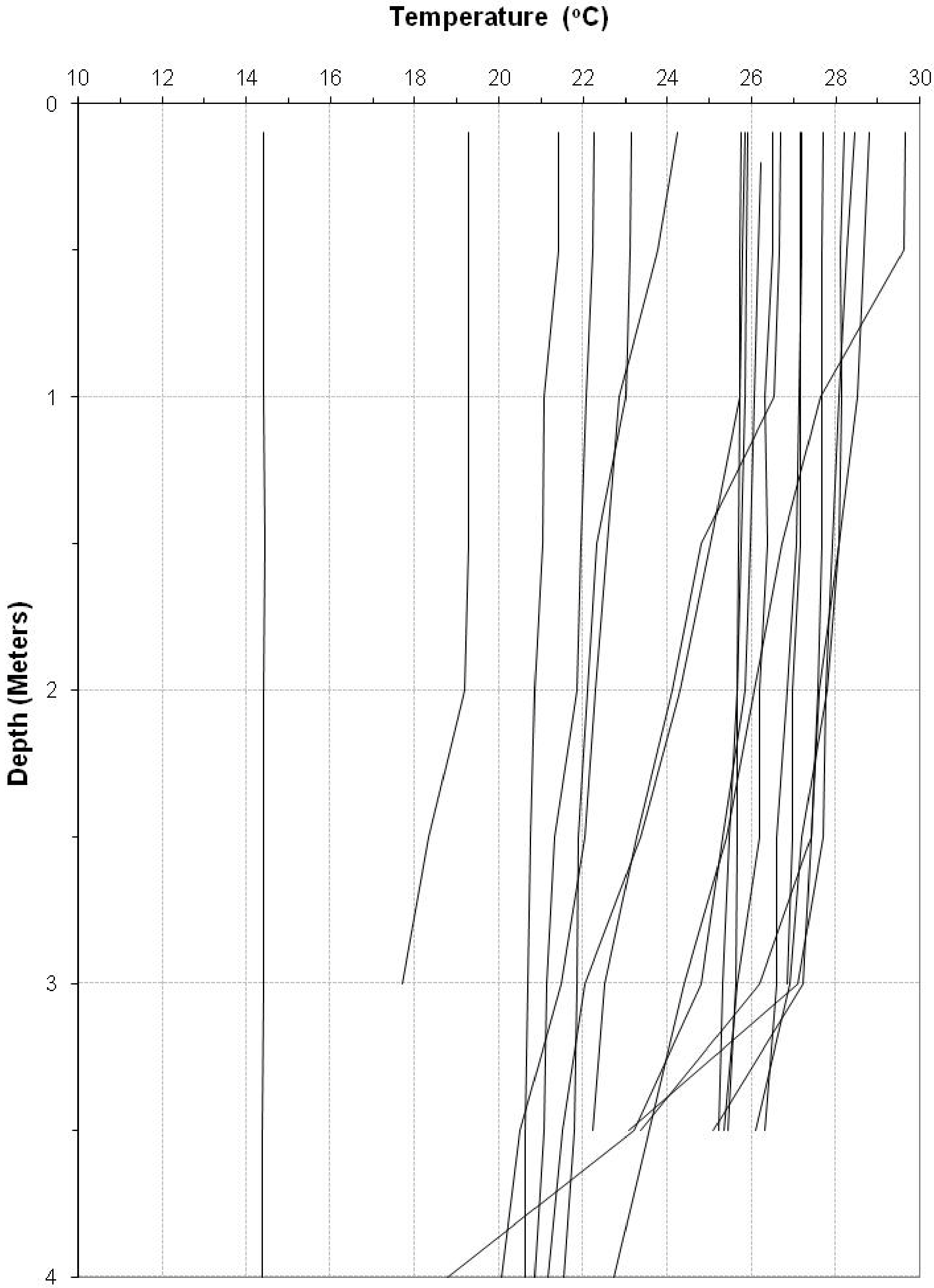


Plate 127. Temperature depth profiles for Holmes Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., HOLLKND1) during the summer over the 5-year period 2006 through 2010.

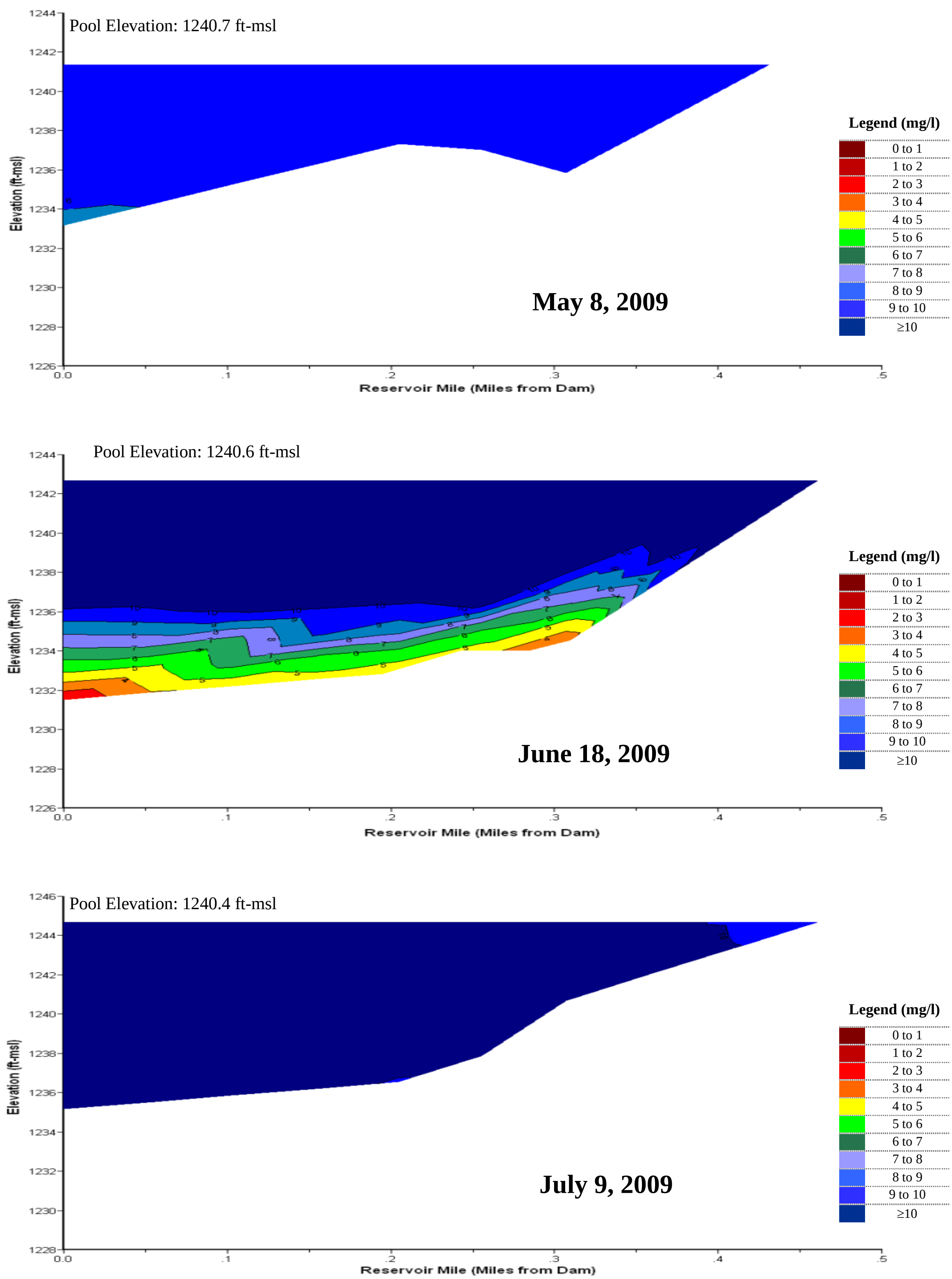
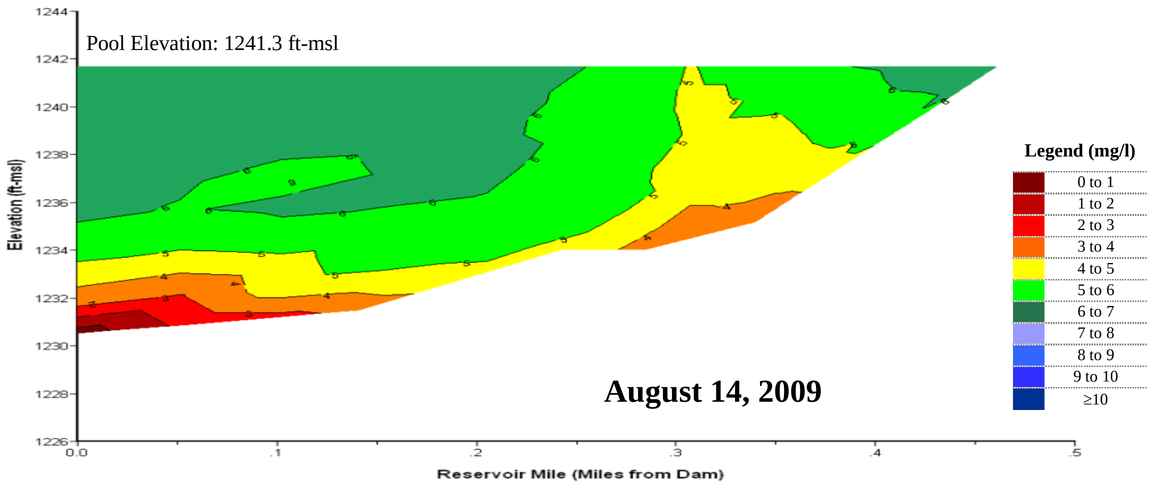


Plate 128. Longitudinal dissolved oxygen (mg/l) contour plots of Holmes Reservoir through the north arm based on depth-profile dissolved oxygen concentrations measured at sites HOLLKND1 and HOLLKMLN1 in 2009.



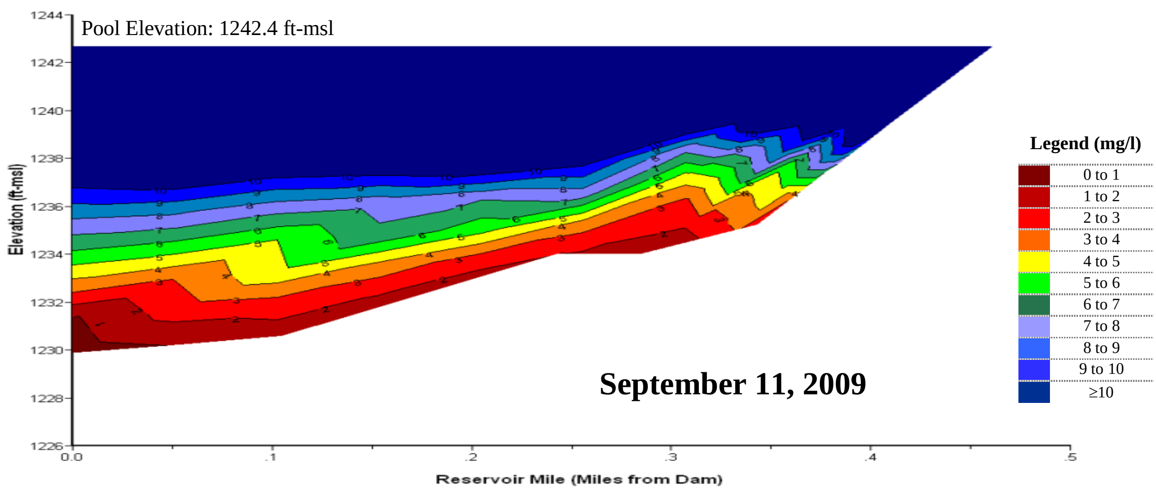


Plate 128. (Continued).

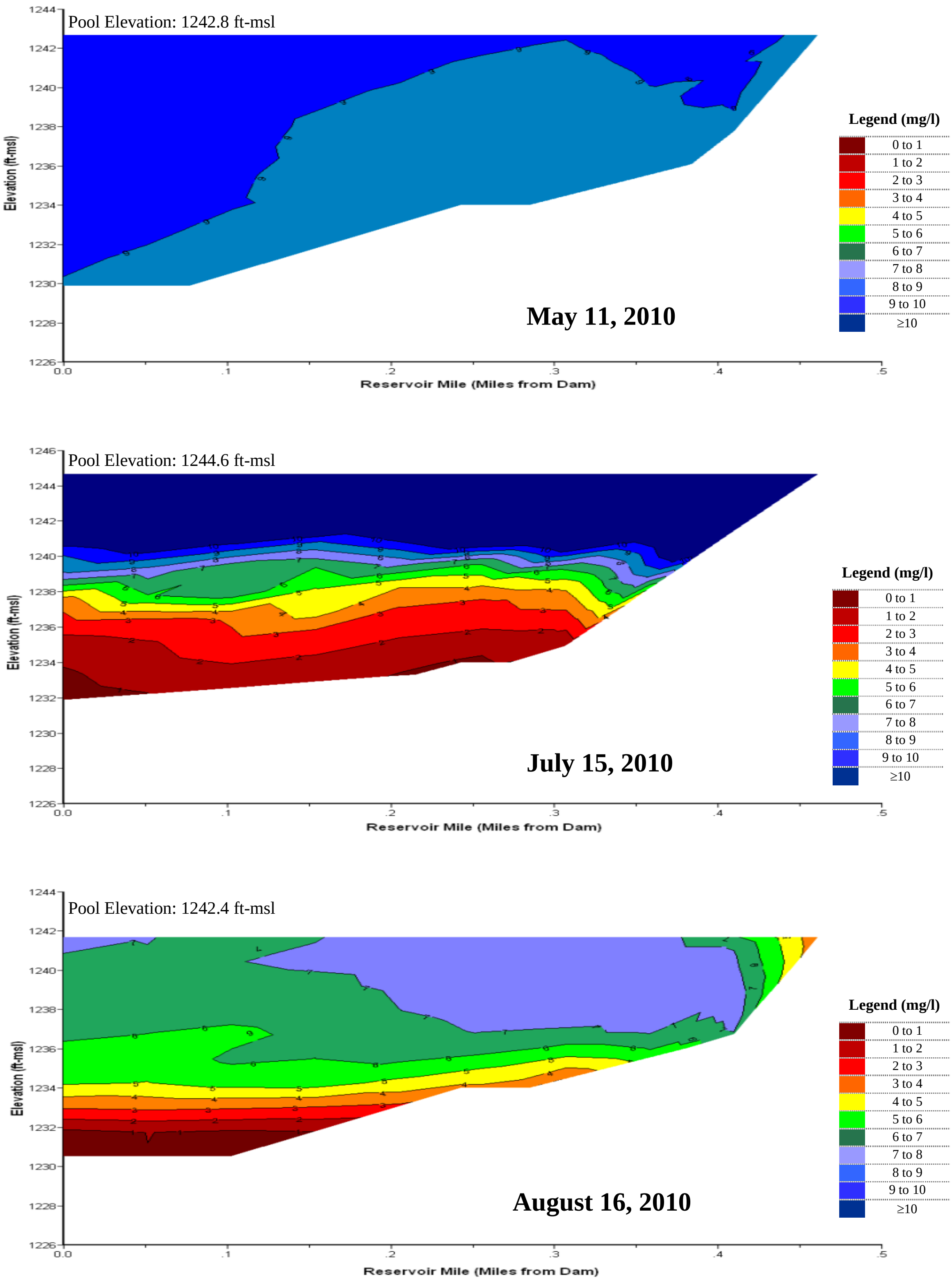


Plate 129. Longitudinal dissolved oxygen (mg/l) contour plots of Holmes Reservoir through the north arm based on depth-profile dissolved oxygen concentrations measured at sites HOLLKND1, HOLLKMLN1, and HOLLKUP1 in 2010.

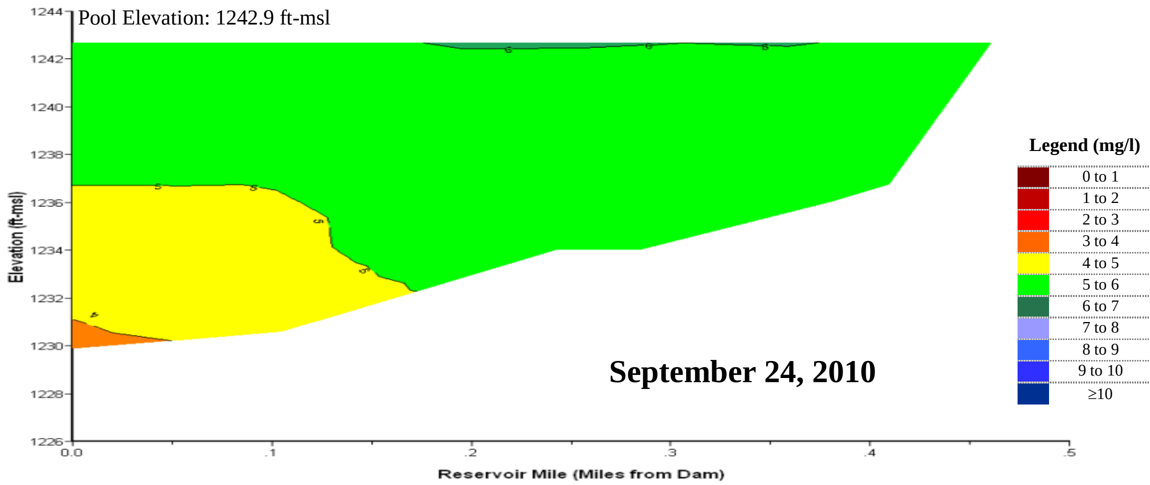


Plate 129. (Continued).

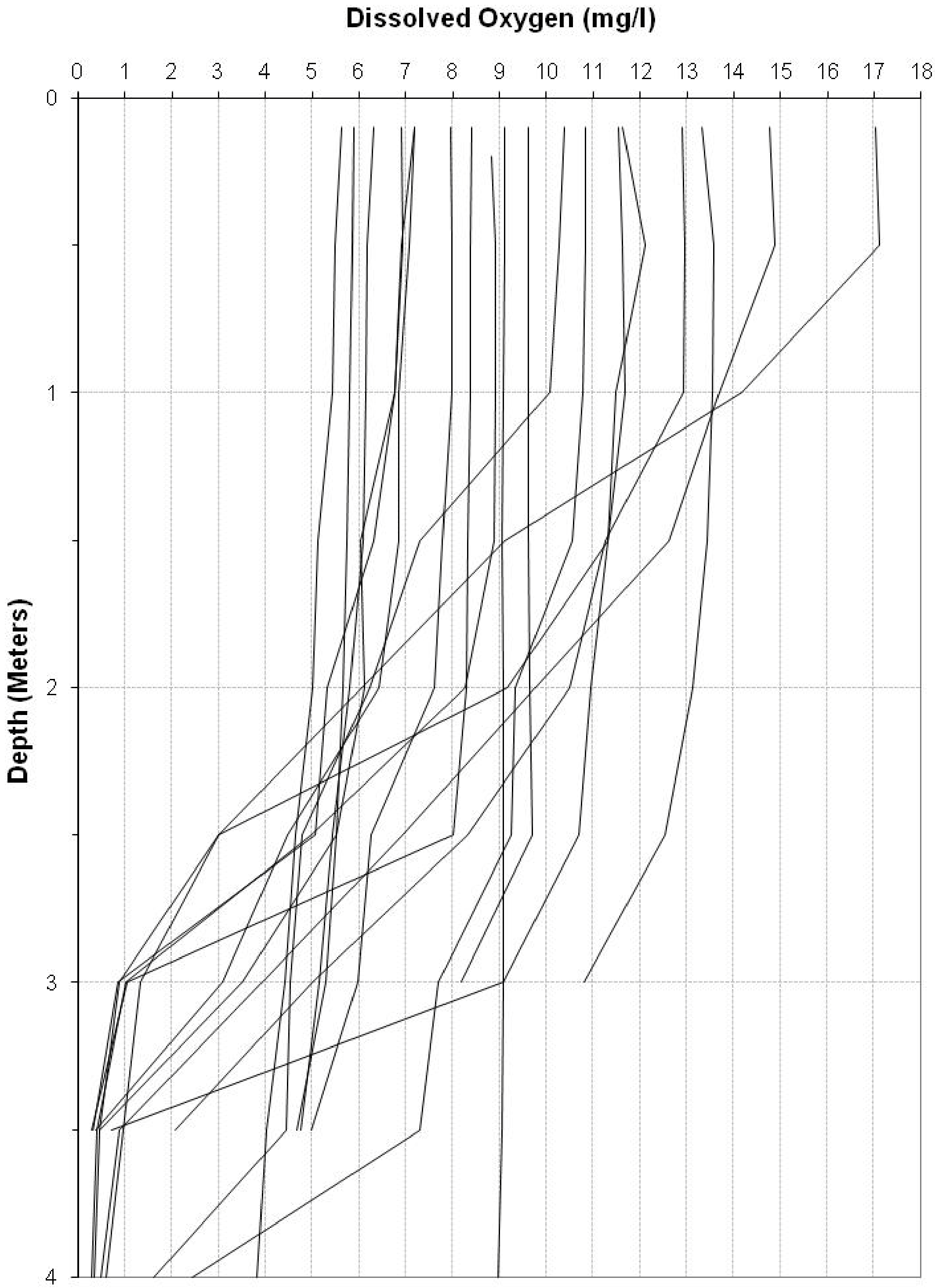


Plate 130. Dissolved oxygen depth profiles for Holmes Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., HOLLKND1) during the summer of the 5-year period 2006 through 2010.

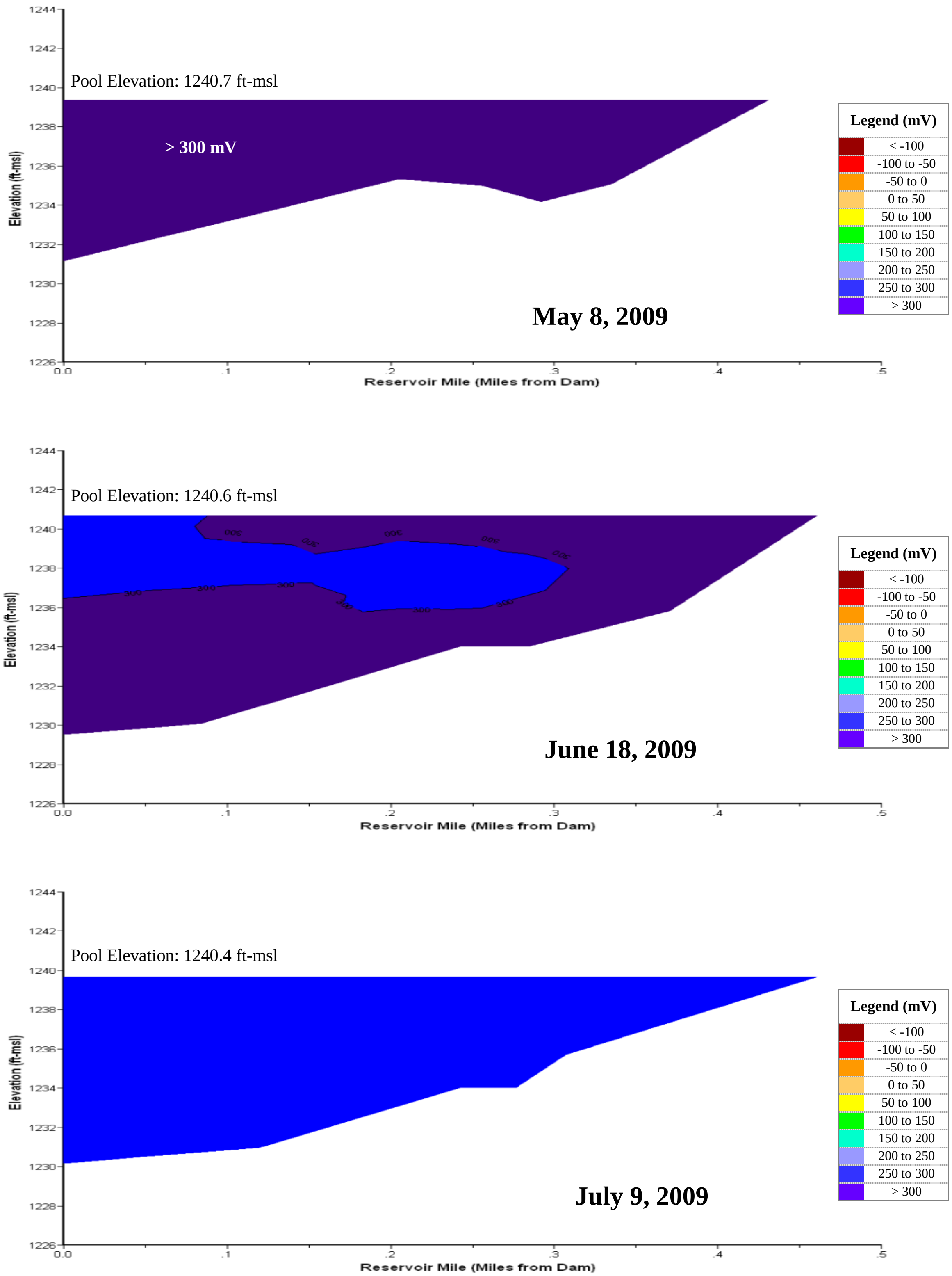
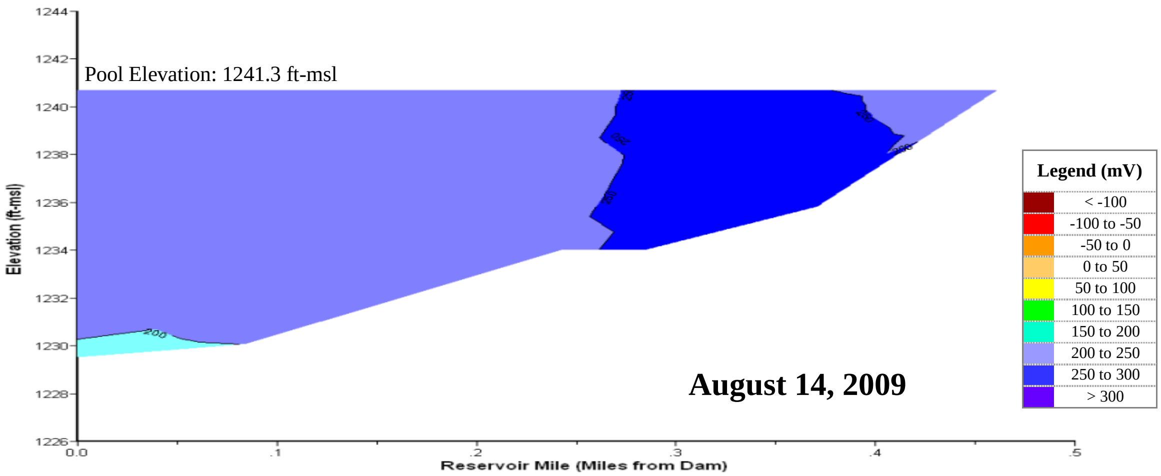


Plate 131. Longitudinal oxidation-reduction potential (mV) contour plots of Holmes Reservoir through the north arm based on depth-profile ORP levels measured at sites HOLLKND1 and HOLLKMLN1 in 2009.



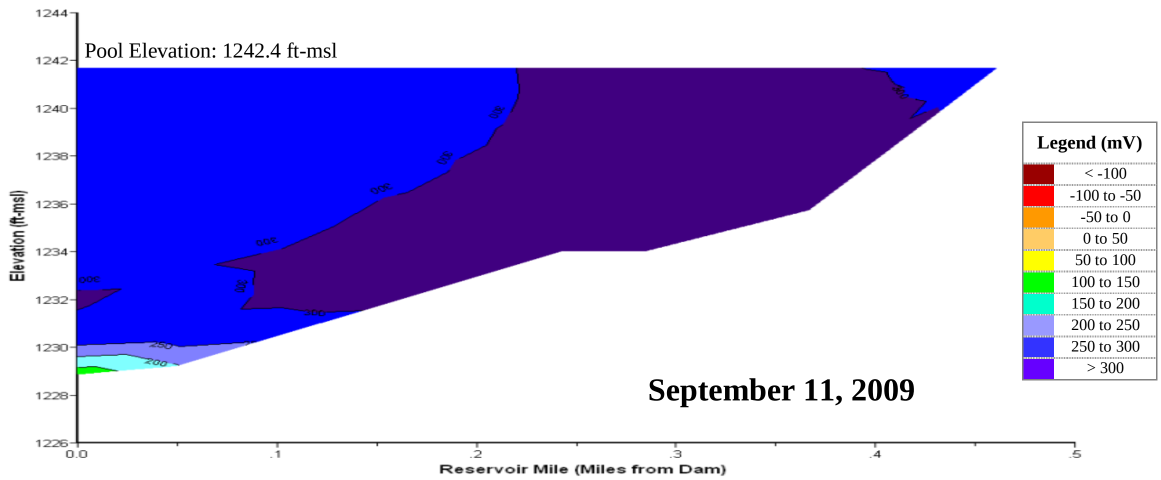


Plate 131. (Continued).

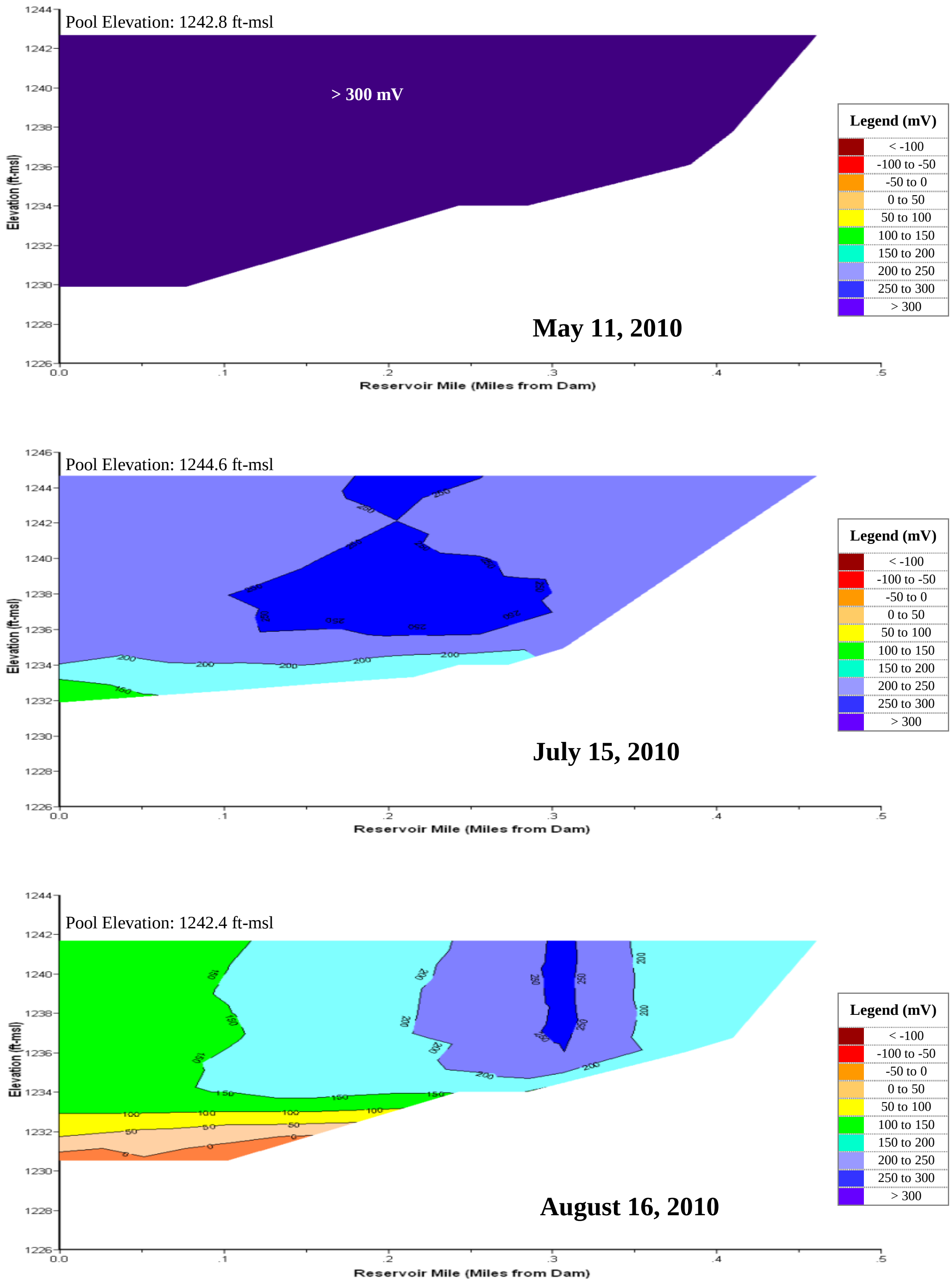


Plate 132. Longitudinal oxidation-reduction potential (mV) contour plots of Holmes Reservoir through the north arm based on depth-profile ORP levels measured at sites HOLLKND1, HOLLKMLN1, and HOLLKUP1 in 2010.

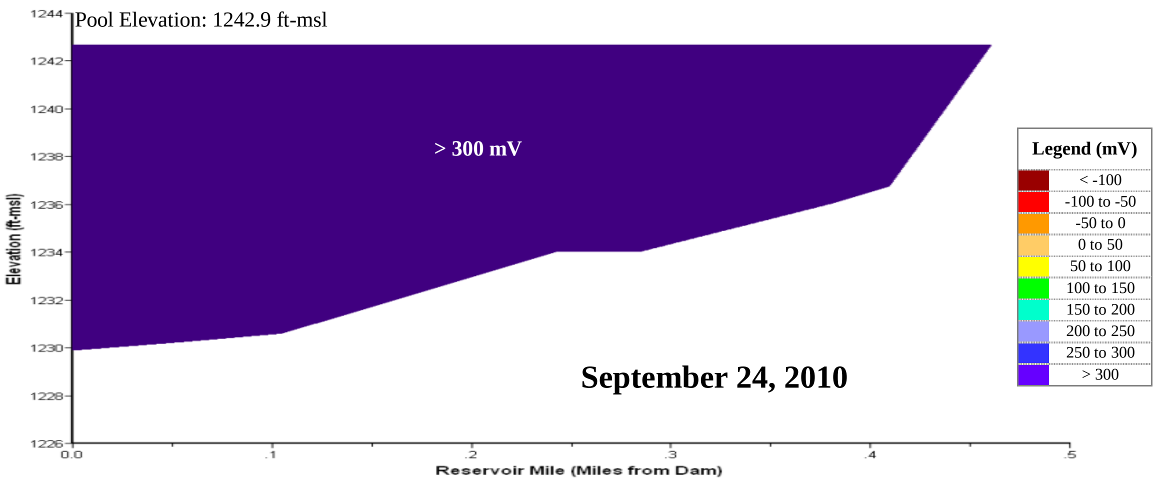


Plate 132. (Continued).

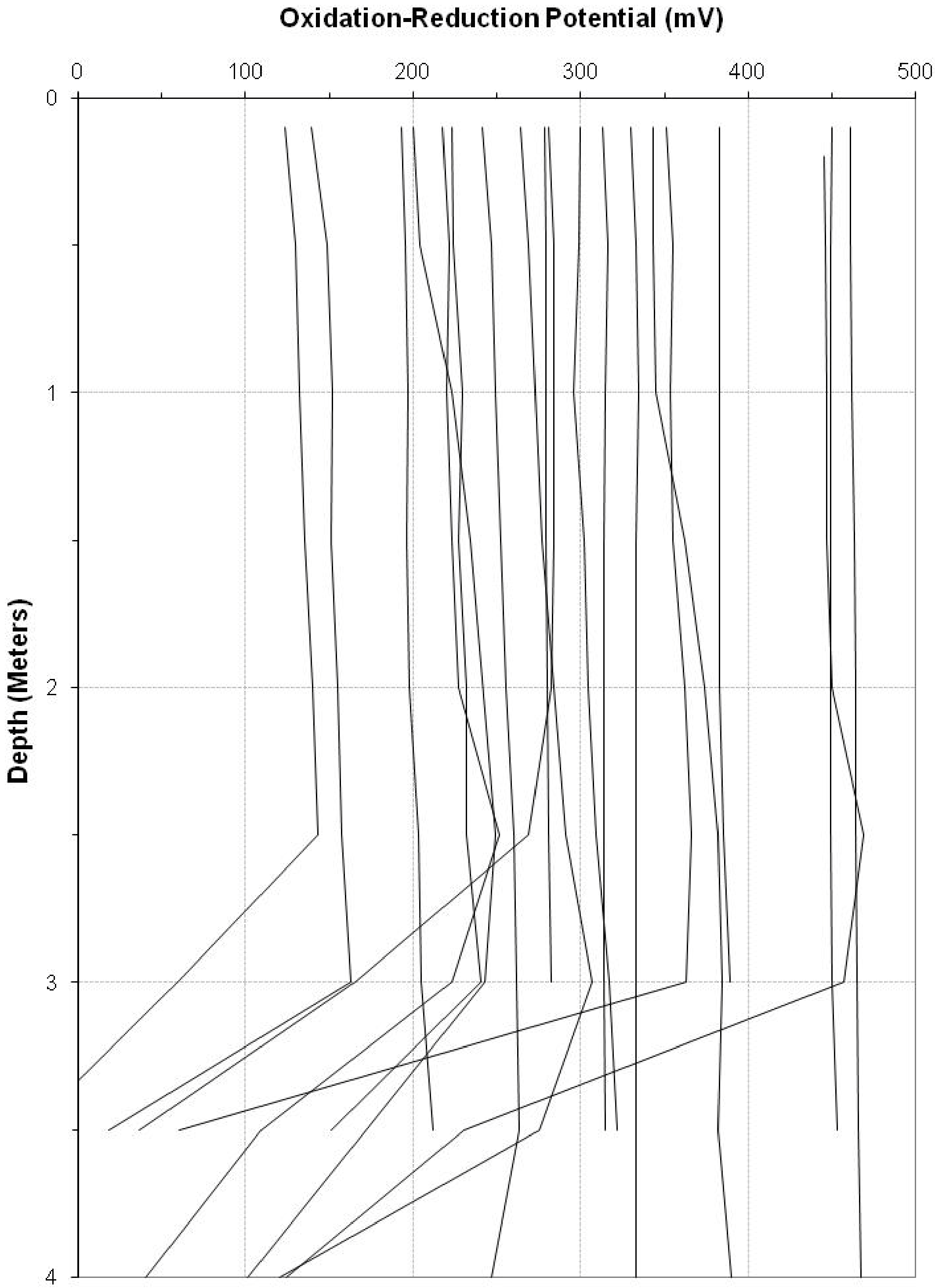


Plate 133. Oxidation-reduction potential depth profiles for Holmes Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., HOLLKND1) during the summer over the 5-year period 2006 through 2010.

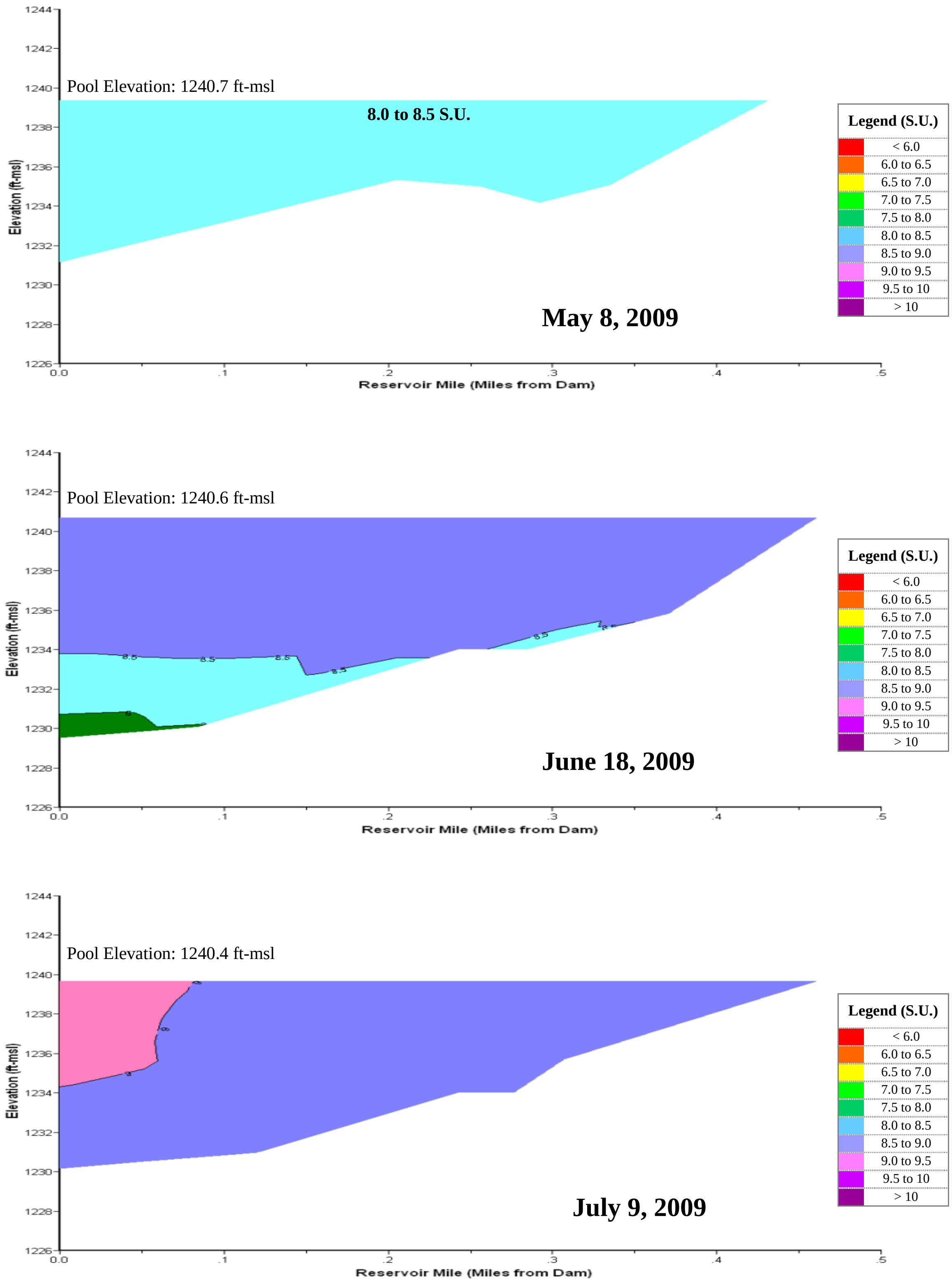
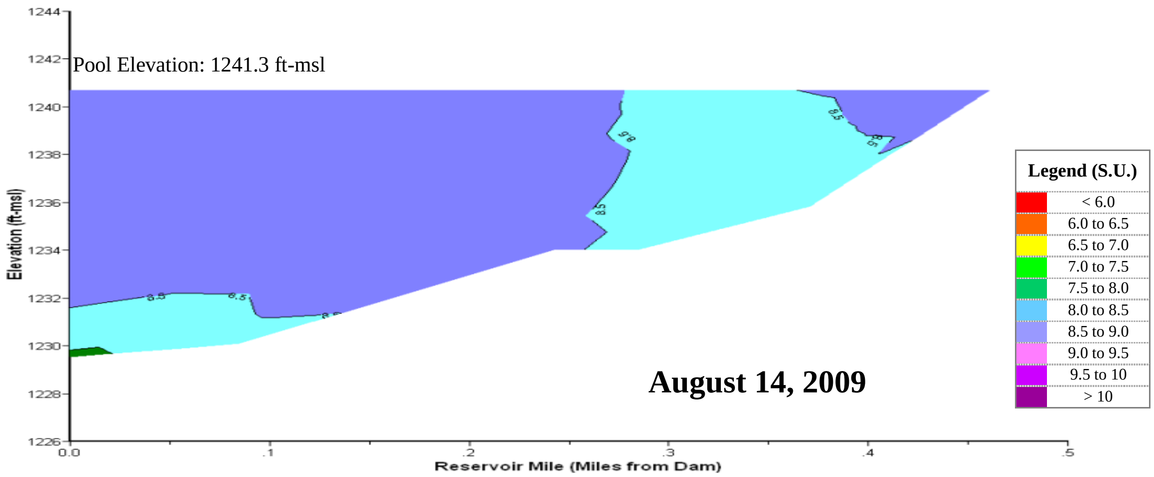


Plate 134. Longitudinal pH (S.U.) contour plots of Holmes Reservoir through the north arm based on depth-profile pH levels measured at sites HOLLKND1 and HOLLKMLN1 in 2009.



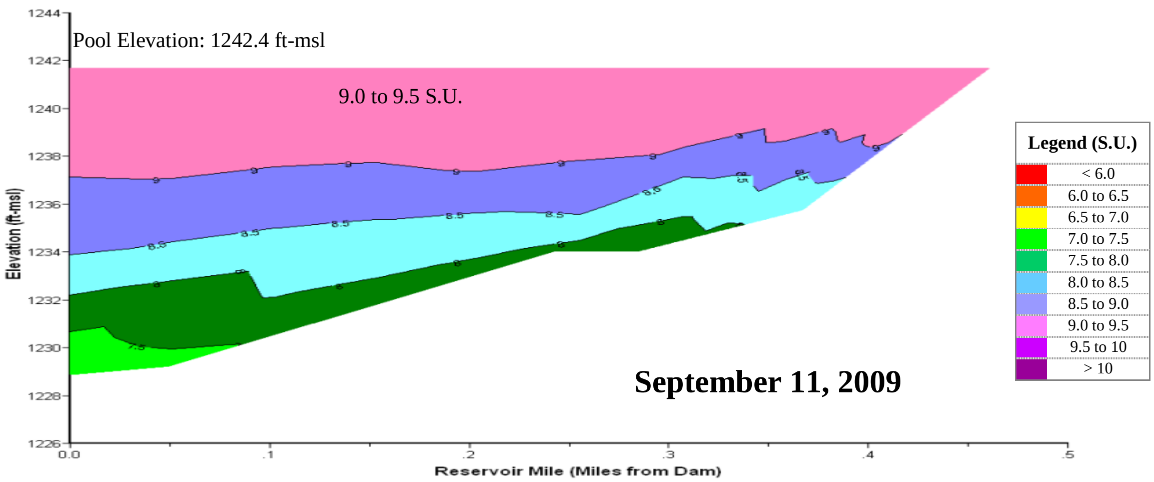


Plate 134. (Continued).

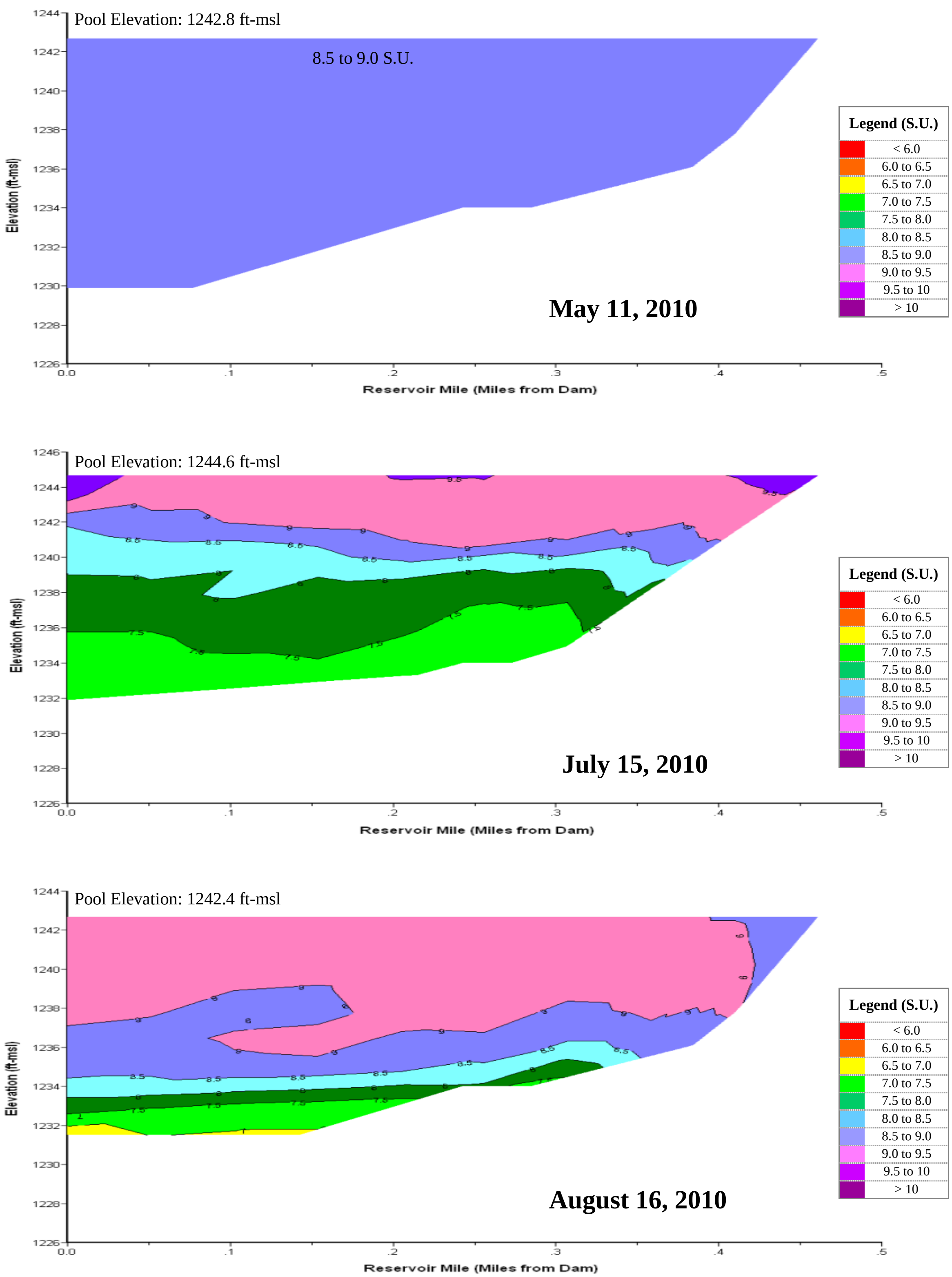


Plate 135. Longitudinal pH (S.U.) contour plots of Holmes Reservoir through the north arm based on depth-profile pH levels measured at sites HOLLKND1, HOLLKMLN1, and HOLLKUP1 in 2010.

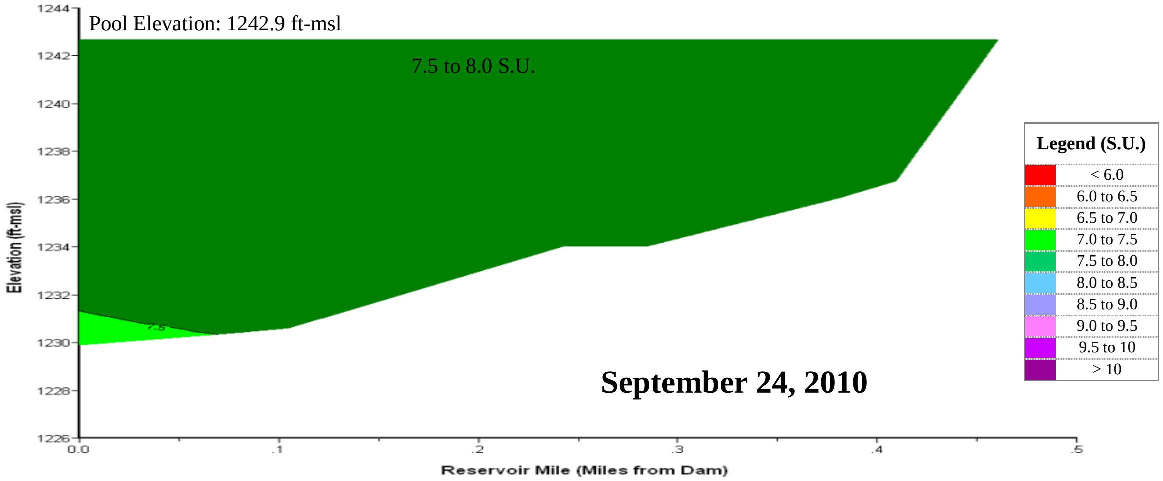


Plate 135. (Continued).

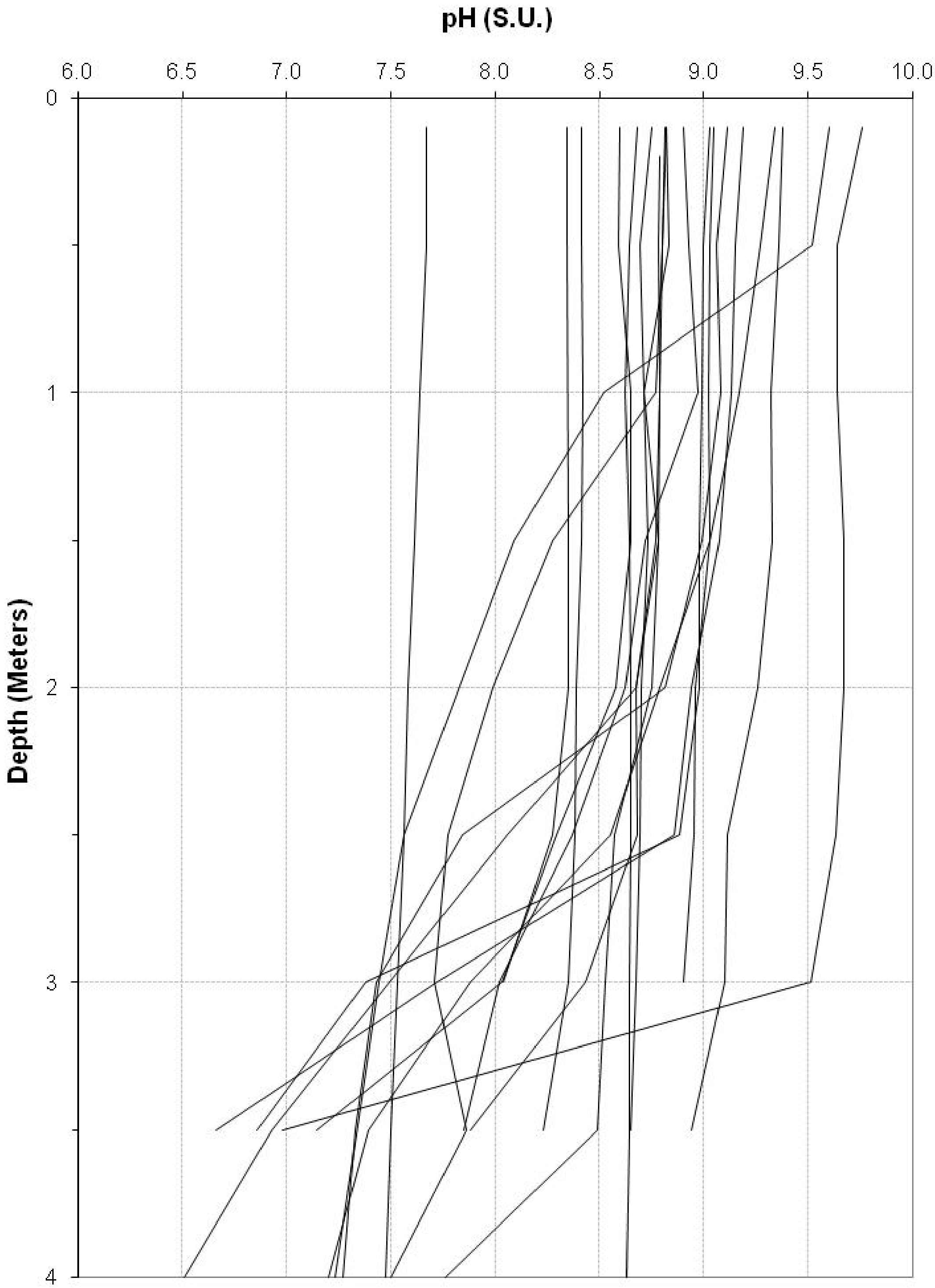


Plate 136. pH depth profiles for Holmes Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., HOLLKND1) during the summer over the 5-year period 2006 through 2010.

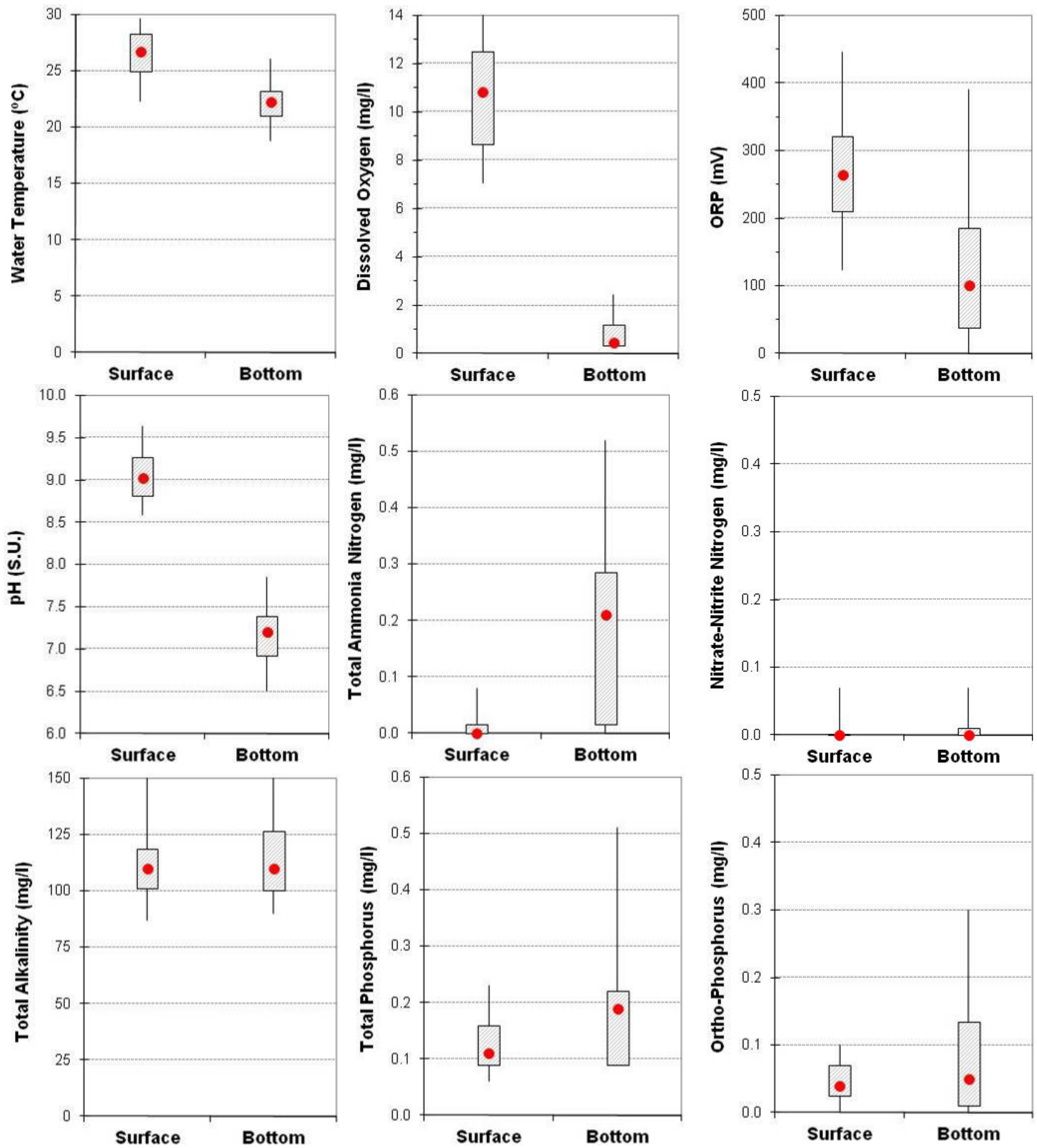


Plate 137. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, alkalinity, total ammonia nitrogen, nitrate-nitrite nitrogen, total phosphorus, and ortho-phosphorus measured in Holmes Reservoir when summer hypoxic conditions were present during the 5-year period 2006 through 2010. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

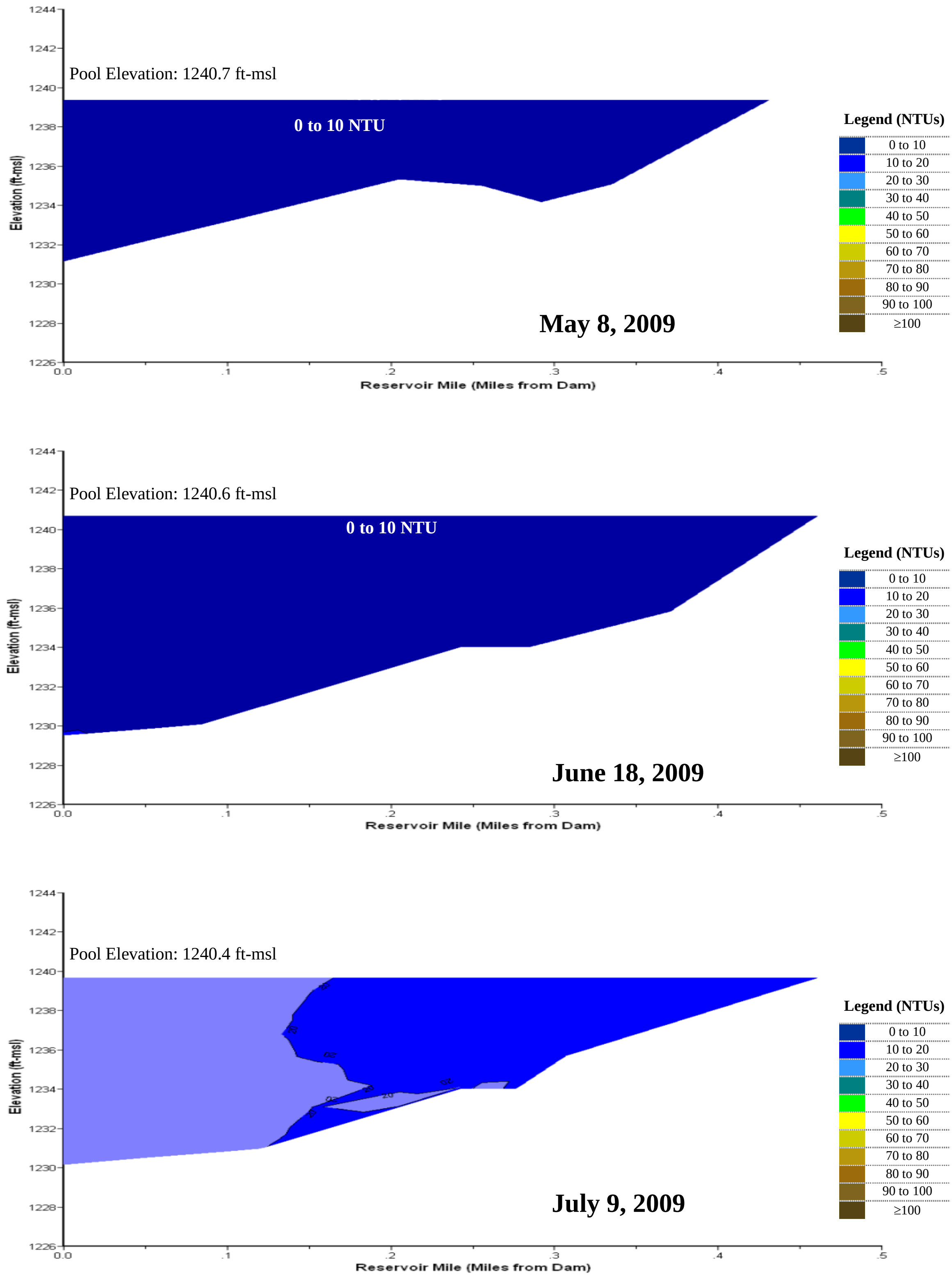
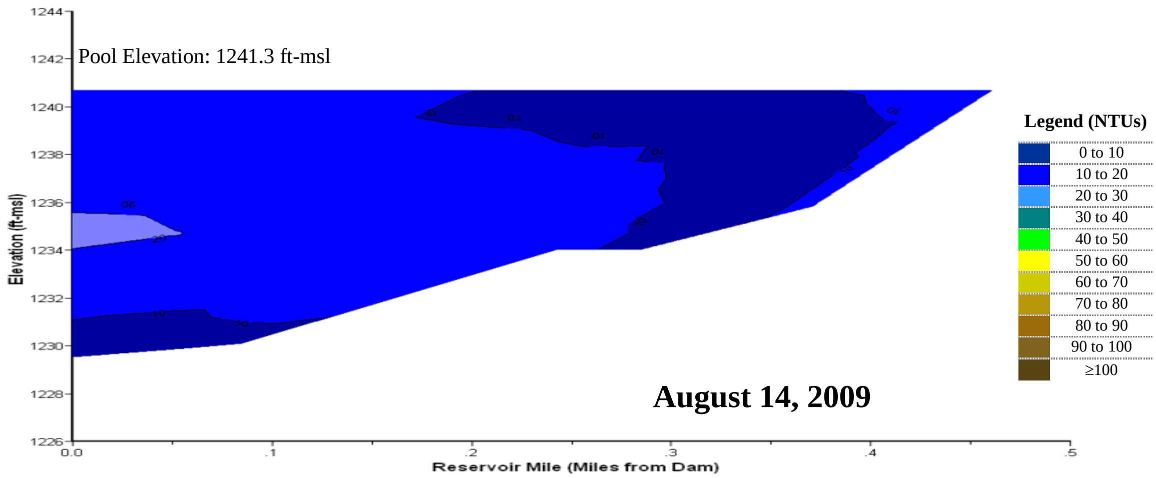


Plate 138. Longitudinal turbidity (NTU) contour plots of Holmes Reservoir through the north arm based on depth-profile turbidity levels measured at sites HOLLKND1 and HOLLKMLN1 in 2010.



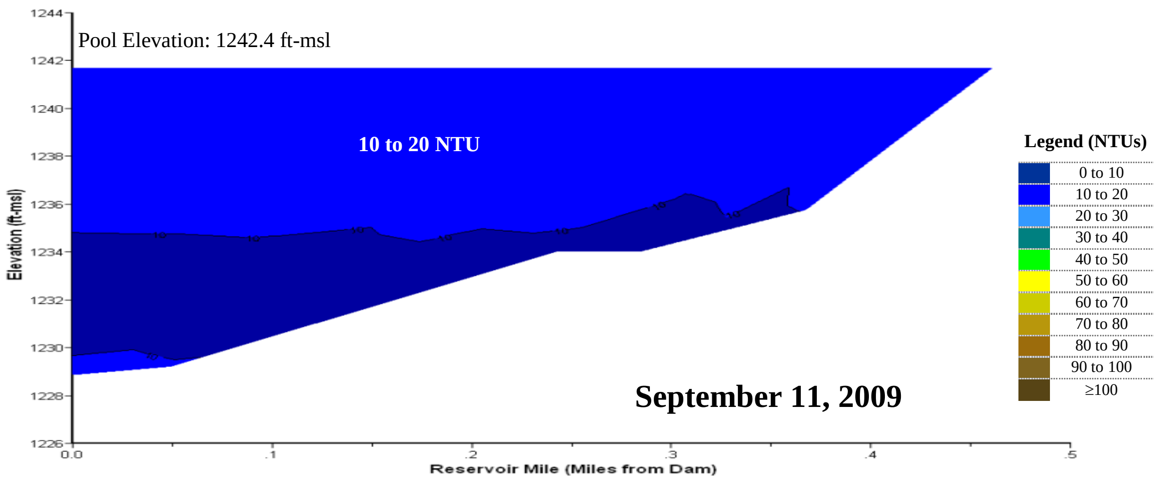
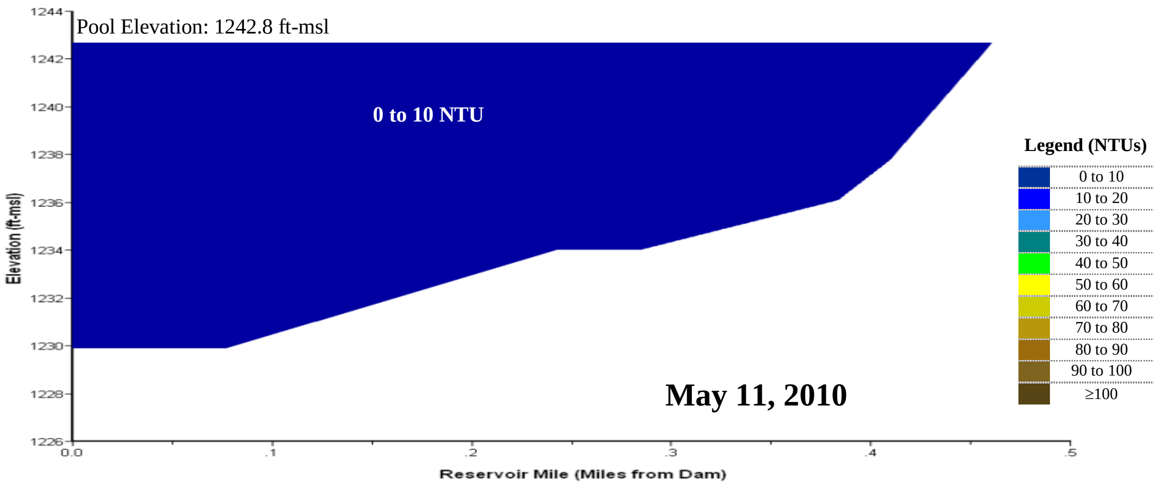
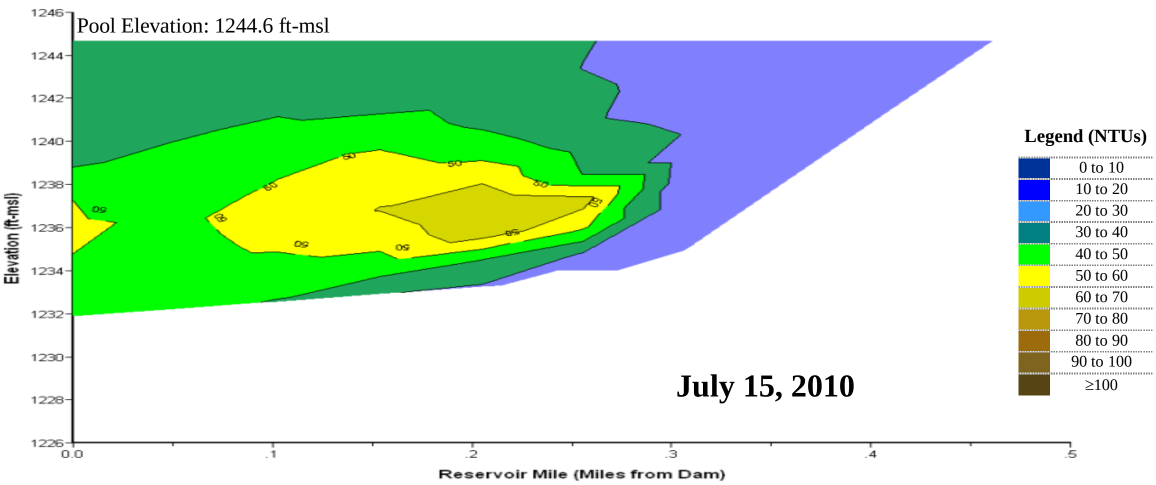


Plate 138. (Continued).





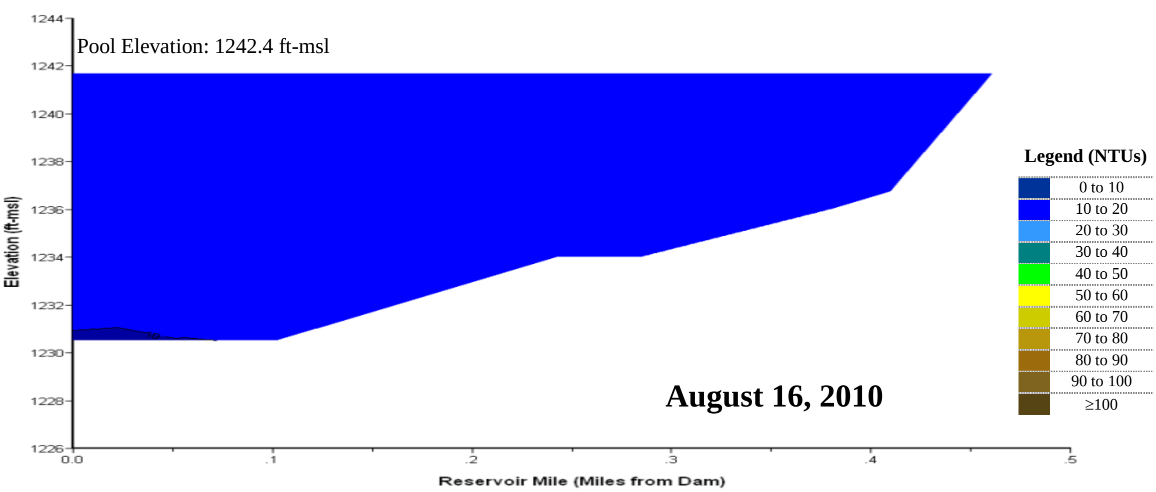


Plate 139. Longitudinal turbidity (NTU) contour plots of Holmes Reservoir through the north arm based on depth-profile turbidity levels measured at sites HOLLKND1, HOLLKMLN1, and HOLLKUP1 in 2010.

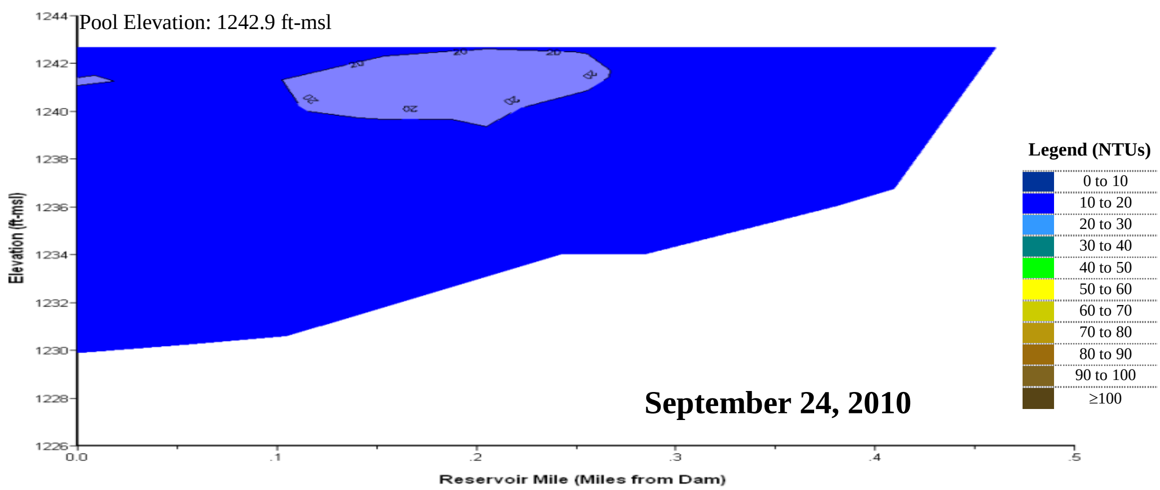


Plate 139. (Continued).

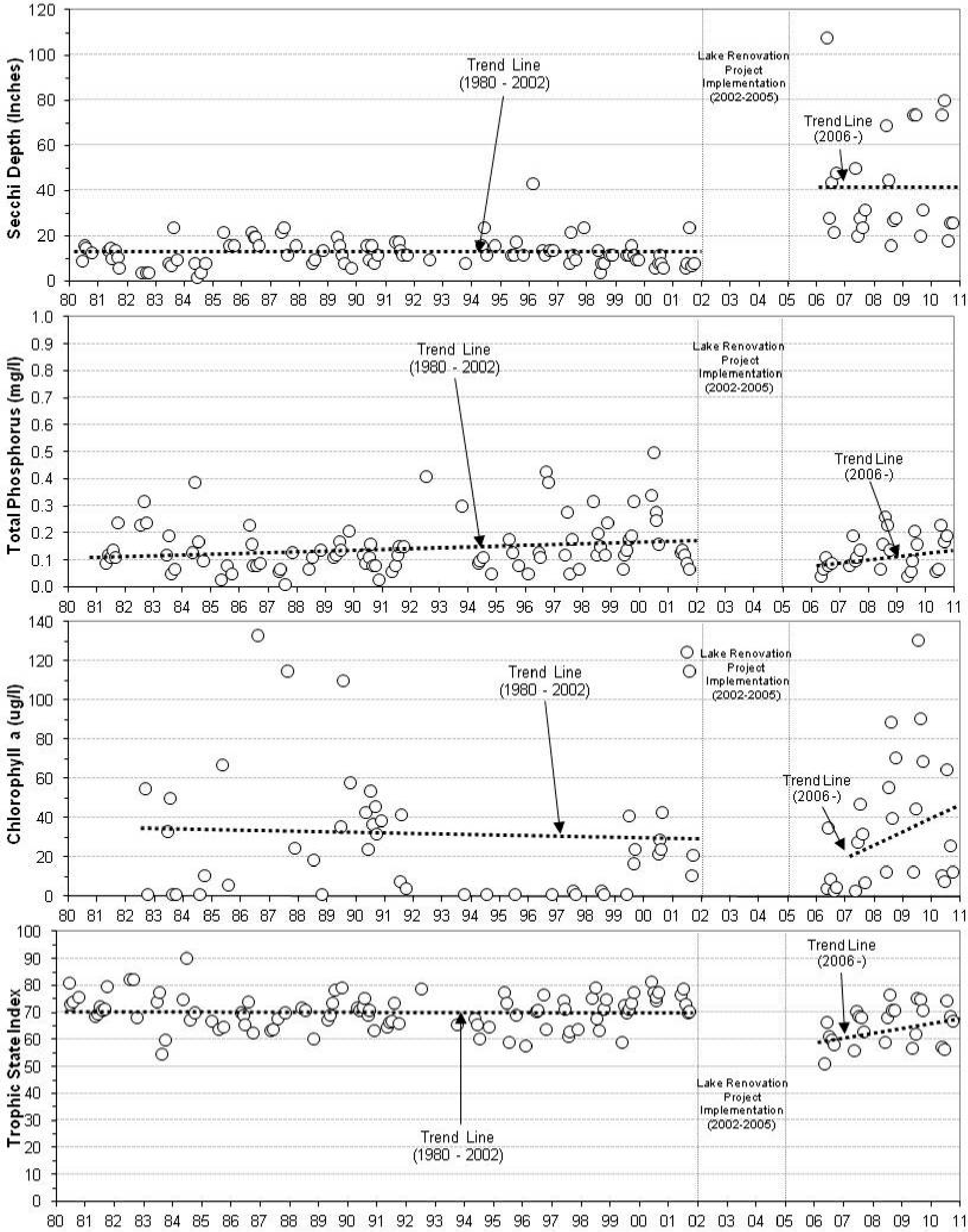


Plate 140. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Holmes Reservoir at the near-dam, ambient site (i.e., site HOLLKND1) over the 31-year period of 1980 through 2010. (Note: lake renovation project implemented from 2002 through 2005).

Plate 141. Summary of runoff water quality conditions monitored in the main west tributary inflow to Holmes Reservoir at monitoring site HOLNFSTH1 during the 5-year period 2004 through 2008**.** Runoff conditions have not been monitored since 2008.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Kjeldahl N, Total (mg/l)	0.1	6	2.0	1.9	0.5	2.1	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	6	0.96	0.79	0.50	2.10	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	6	0.44	0.37	0.29	0.72	-----	-----	-----
Suspended Solids, Total (mg/l)	4	6	99	48	19	242	-----	-----	-----
Acetochlor, Total (ug/l)(C)	0.05	3	-----	0.50	n.d	5.61	-----	-----	-----
Atrazine, Total (ug/l)(C)	0.05	3	0.46	0.28	0.24	0.86	330(1), 12(2)	0	0%
Metolachlor, Total (ug/l)(C)	0.05	3	0.22	0.24	0.19	0.24	390(1), 100(2)	0	0%
E. coli (cfu/100ml)	1	12	11,092	7,933	548	25,000	-----	-----	-----

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Acute criterion for aquatic life.
(2) Chronic criterion for aquatic life.
(C) Immunoassay analysis.

Plate 142. Summary of runoff water quality conditions monitored in the main east tributary inflow to Holmes Reservoir at monitoring site HOLNFEST1 during the 5-year period 2004 through 2008**.** Runoff conditions have not been monitored since 2008.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Kjeldahl N, Total (mg/l)	0.1	8	1.5	1.6	0.8	2.0	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	8	0.28	0.29	n.d.	0.57	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	8	0.38	0.35	0.14	0.66	-----	-----	-----
Suspended Solids, Total (mg/l)	4	8	183	184	15	516	-----	-----	-----
Acetochlor , Total (ug/l)(C)	0.05	4	-----	0.16	n.d.	0.28	-----	-----	-----
Atrazine, Total (ug/l)(C)	0.05	5	0.48	0.49	0.28	0.70	330(1), 12(2)	0	0%
Metolachlor, Total (ug/l)(C)	0.05	5	0.20	0.18	0.05	0.47	390(1), 100(2)	0	0%
E. coli (cfu/100ml)	1	13	4,810	2,489	5	14,136	-----	-----	-----

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Acute criterion for aquatic life.
(2) Chronic criterion for aquatic life.
(C) Immunoassay analysis.

Plate 143. Summary of water quality conditions monitored in Olive Creek Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site OCRLKND1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	25	1332.6	1333.4	1328.1	1336.0	-----	-----	-----
Water Temperature (°C)	0.1	144	23.9	25.0	16.6	28.8	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	143	7.5	7.7	0.2	14.3	≥ 5[2]	21	15%*
Dissolved Oxygen (% Sat.)	0.1	140	93.0	93.4	2.7	179.8	-----	-----	-----
Specific Conductance (umho/cm)	1	140	265	260	191	335	2,000[3]	0	0%
pH (S.U.)	0.1	140	8.7	8.5	7.3	9.9	≥6.5 & ≤9.0[1]	55	39%*
Turbidity (NTUs)	1	140	52	41	3	598	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	140	306	301	60	511	-----	-----	-----
Secchi Depth (in.)	1	25	17	15	8	56	-----	-----	-----
Alkalinity, Total (mg/l)	7	47	126	125	94	170	20[1]	0	0%
Ammonia, Total (mg/l)	0.02	47	-----	0.11	n.d.	0.65	2.65 [4,5], 0.47 [4,6]	0, 3	0%,6%*
Chlorophyll *a* (ug/l) – Field Probe	1	123	36	16	3	150	10[7]	85	69%
Chlorophyll *a* (ug/l) – Lab Determined	1	25	48	32	n.d.	150	10[7]	19	76%
Hardness, Total (mg/l)	0.4	5	110.8	114	87	130	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	47	2.1	1.8	0.7	3.8	-----	-----	-----
Nitrogen, Total (mg/)	0.1	47	2.3	2.2	0.7	3.8	1 [7]	45	95%
Nitrate-Nitrite N, Total (mg/l)	0.02	47	-----	n.d.	n.d.	1.5	100[3]	0	0%
Phosphorus, Total (mg/l)	0.1	47	0.4	0.3	0.1	0.8	0.05[7]	47	100%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	47	0.15	0.12	n.d.	0.65	-----	-----	-----
Suspended Solids, Total (mg/l)	4	47	21	19	n.d.	55	-----	-----	-----
Aluminum, Dissolved (ug/l)	25	5	-----	37	n.d.	72	750[5], 87[6]	0	0%
Antimony, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	88[5], 30[6]	0	0%
Arsenic, Dissolved (ug/l)	3	5	29	26	13	59	340[5], 16.7[8]	0,3	0%, 60%*
Beryllium, Dissolved (ug/l)	3	5	-----	n.d.	n.d.	n.d.	130[5], 5.3[6]	0	0%
Cadmium, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	6.7[5], 0.3[6]	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	659[5], 86[6]	0	0%
Copper, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	15[5], 10[6]	0	0%
Lead, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	74[5], 2.9[6]	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4[5]	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77[6]	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	3	523[5], 58[6]	0	0%
Selenium, Total (ug/l)	2	5	-----	n.d.	n.d.	31	20[3,5], 5[6]	1	20%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	4.3[5]	0	0%
Thallium (ug/l)	3	5	-----	n.d.	n.d.	n.d.	1,400[5], 6.3[8]	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	131[5,6]	0	0%
Microcystin, Total (ug/l)	0.05	25	0.33	n.d.	n.d.	3.2	20[9]	0	0%
Acetochlor, Total (ug/l)[C]	0.05	15	-----	0.6	n.d.	1.6	-----	-----	-----
Alachlor, Total (ug/l)[C]	0.05	10	0.24	0.2	n.d.	0.44	760[5], 76[6]	0	0%
Atrazine, Total (ug/l)[C]	0.05	25	2.28	2	n.d.	4.6	330[5], 12[6]	0	0%
Metolachlor, Total (ug/l)[C]	0.05	25	0.85	0.5	n.d.	4.6	390[5], 100[6]	0	0%
Pesticide Scan (ug/l)[D]	0.05						-----	-----	-----
Acetochlor		5	-----	n.d.	n.d.	0.65	-----	-----	-----
Atrazine		5	-----	1.2	n.d.	6	330[5], 12[6]	0	0%
Deethylatrazine		4	-----	0.45	n.d.	1.5	-----	-----	-----
Deisopropylatrazine		4	-----	n.d.	n.d.	0.2	-----	-----	-----
Metolachlor		5	-----	n.d.	n.d.	1.4	390[5], 100[6]	0	0%

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l microcystins in recreation water for impairment assessment.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 144. Summary of water quality conditions monitored in Olive Creek Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site OCRLKML1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, and ORP are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	34	1332.5	1333.4	1328.1	1336.0	-----	-----	-----
Water Temperature (°C)	0.1	160	23.4	23.4	16.4	28.8	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	160	7.1	7.1	0.3	13.1	≥ 5[2]	17	16%
Dissolved Oxygen (% Sat.)	0.1	157	86.9	89.2	3.3	177.3	-----	-----	-----
Specific Conductance (umho/cm)	1	157	252	256	2	324	2,000[3]	0	0%
pH (S.U.)	0.1	157	8.6	8.4	7.3	9.9	≥6.5 & ≤9.0[1]	46	44%*
Turbidity (NTUs)	1	143	49	45	3	414	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	151	340	339	-12	506	-----	-----	-----
Secchi Depth (in.)	1	35	15	14	3	52	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	124	32	15	2	158	16[4]	17	24%

n.d. = Not detected.
[A] Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).
[B] [1] General criteria for aquatic life.
[2] Use-specific criteria for aquatic life.
[3] Agricultural criteria for surface waters.
[4] Nutrient criteria for aquatic life.
* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

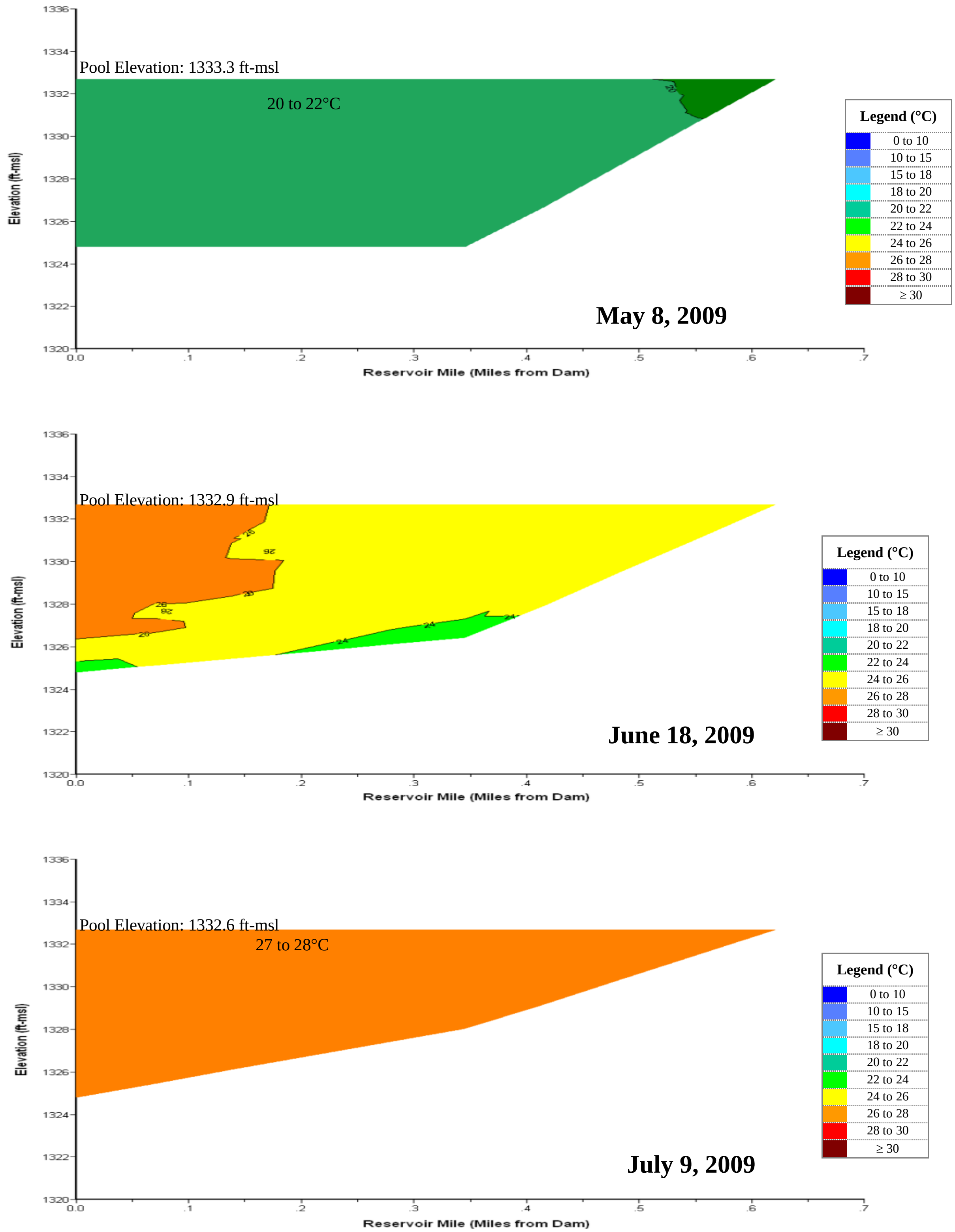
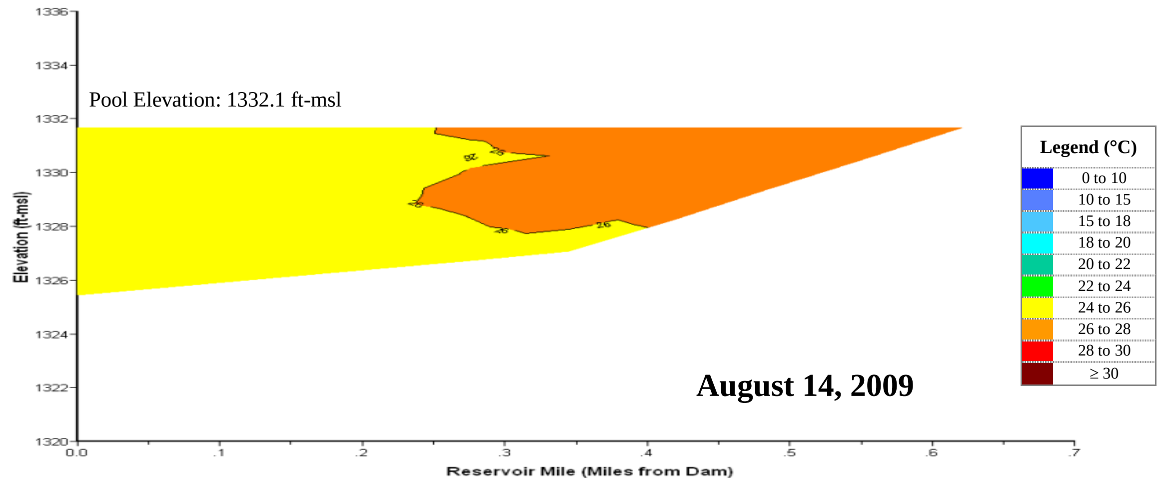


Plate 145. Longitudinal water temperature (°C) contour plots of Olive Creek Reservoir based on depth-profile water temperatures measured at sites OCRLKND1 and OCRLKML1 in 2009.



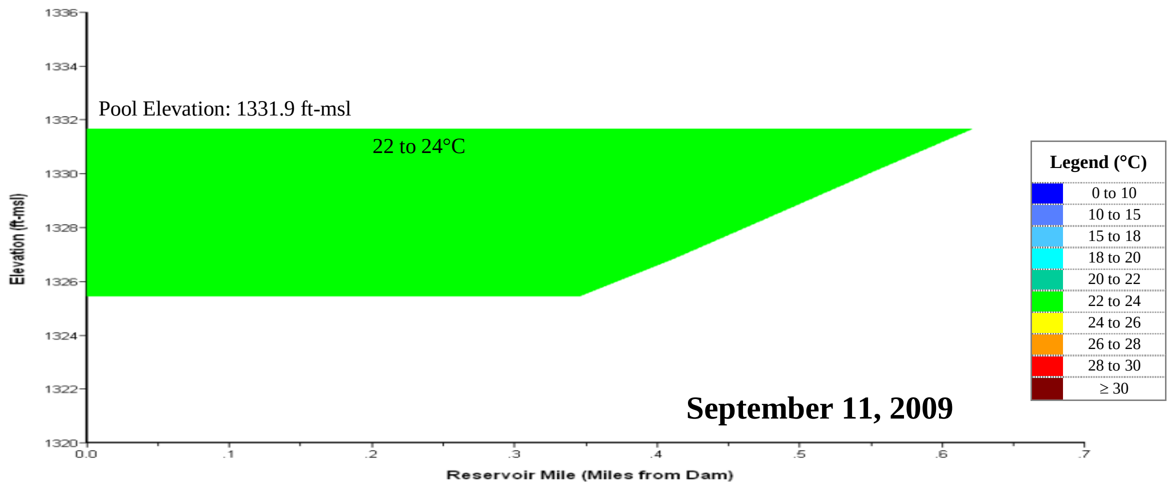


Plate 145. (Continued).

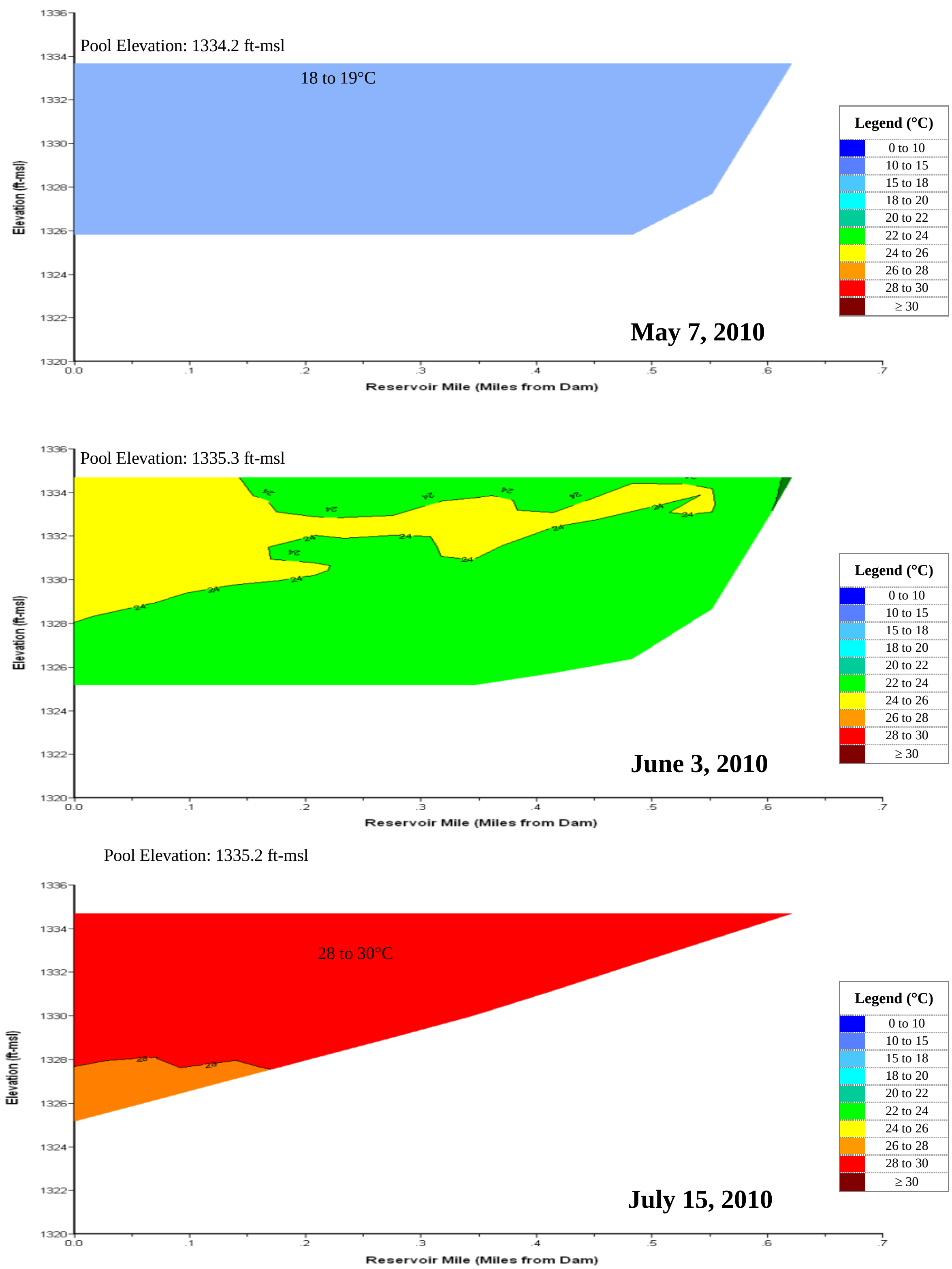
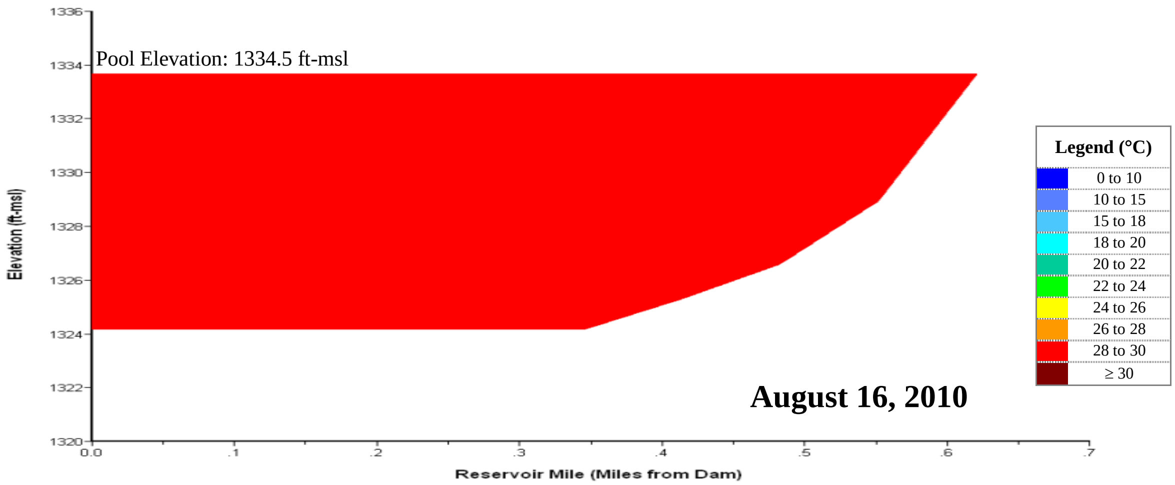


Plate 146. Longitudinal water temperature (°C) contour plots of Olive Creek based on depth-profile water temperatures measured at sites OCRLKND1, OCRLKML1, and OCRLKUP1 in 2010.



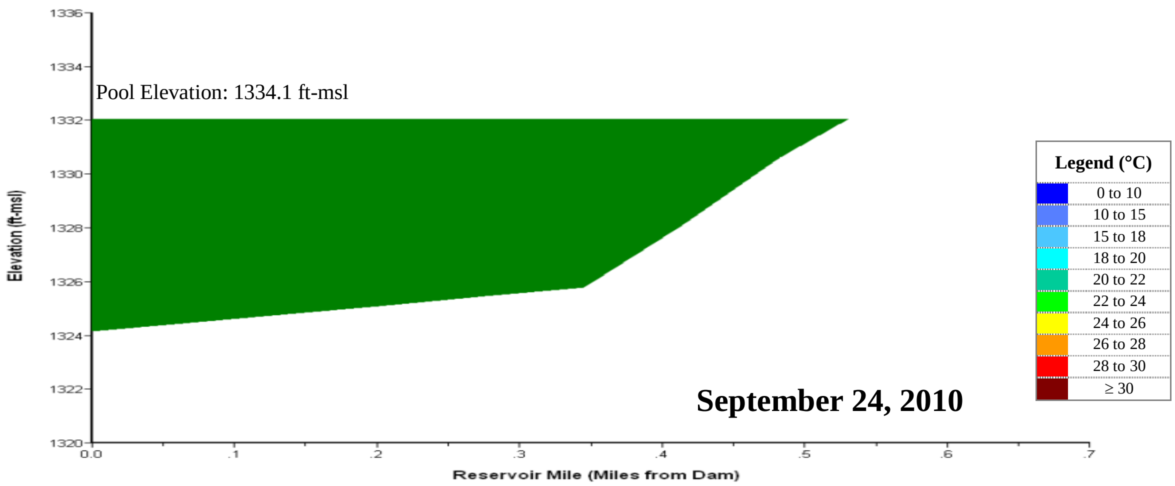


Plate 146. (Continued).

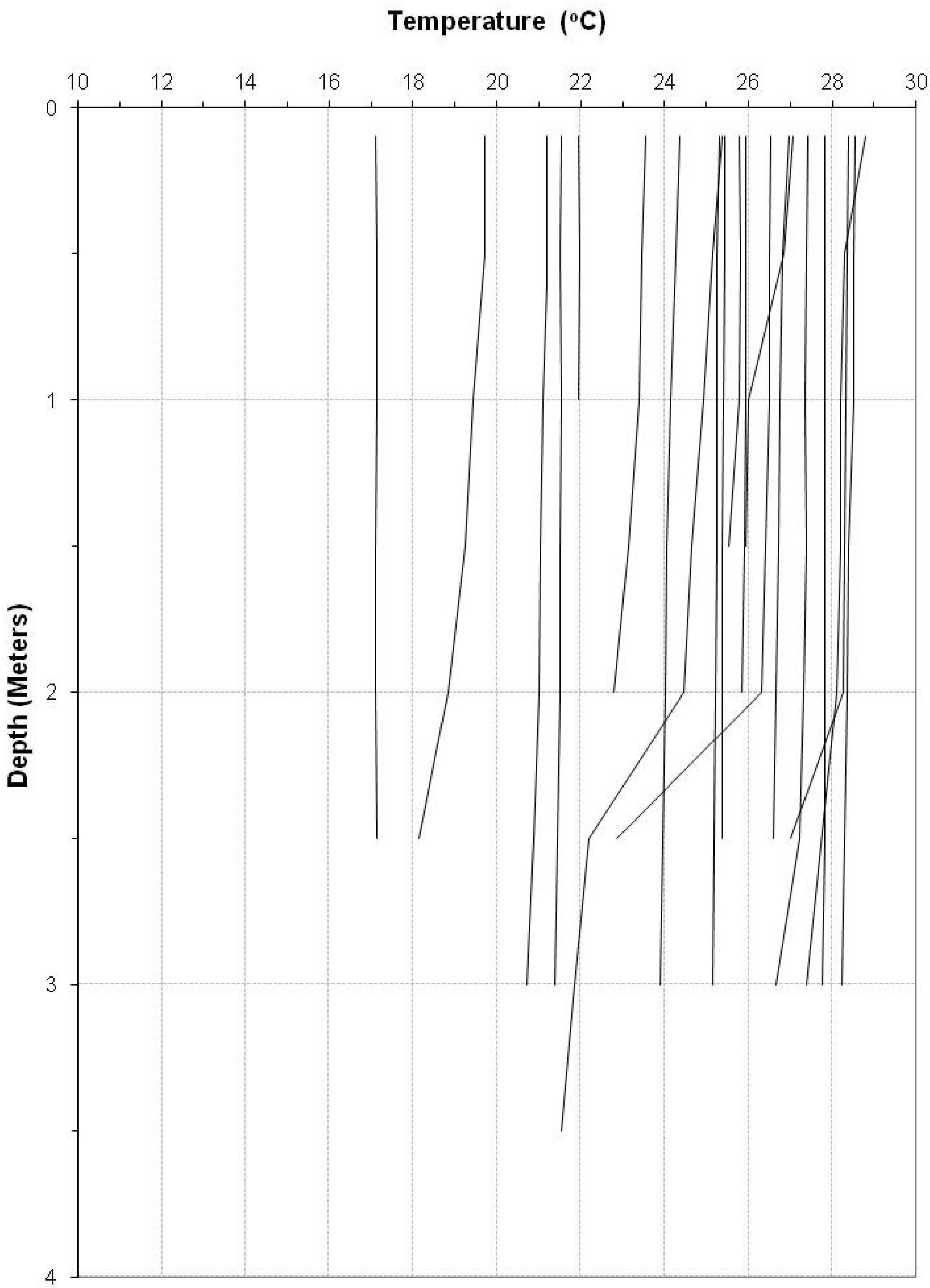


Plate 147. Temperature depth profiles for Olive Creek Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., OCRLKND1) during the summer over the 5-year period of 2006 through 2010.

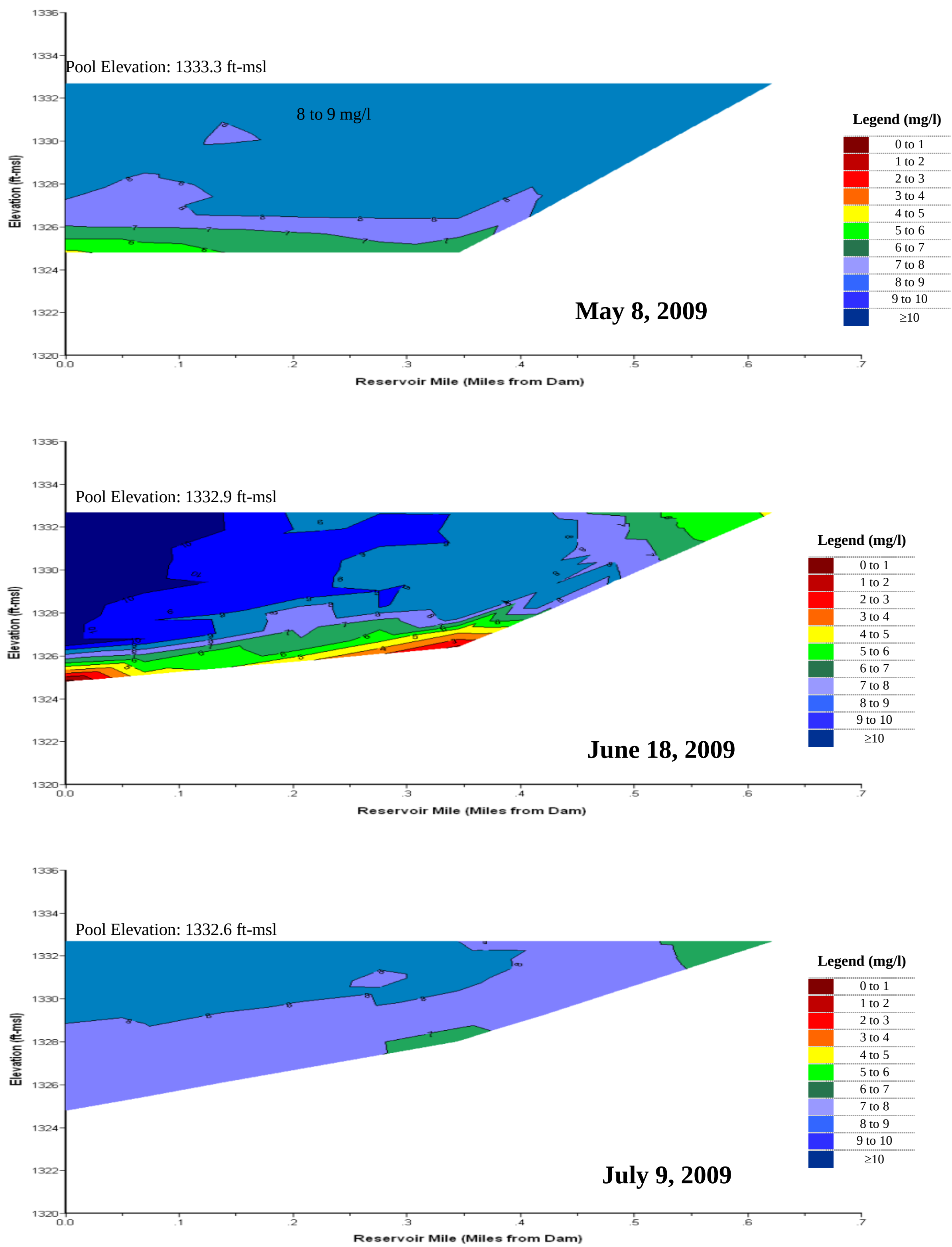
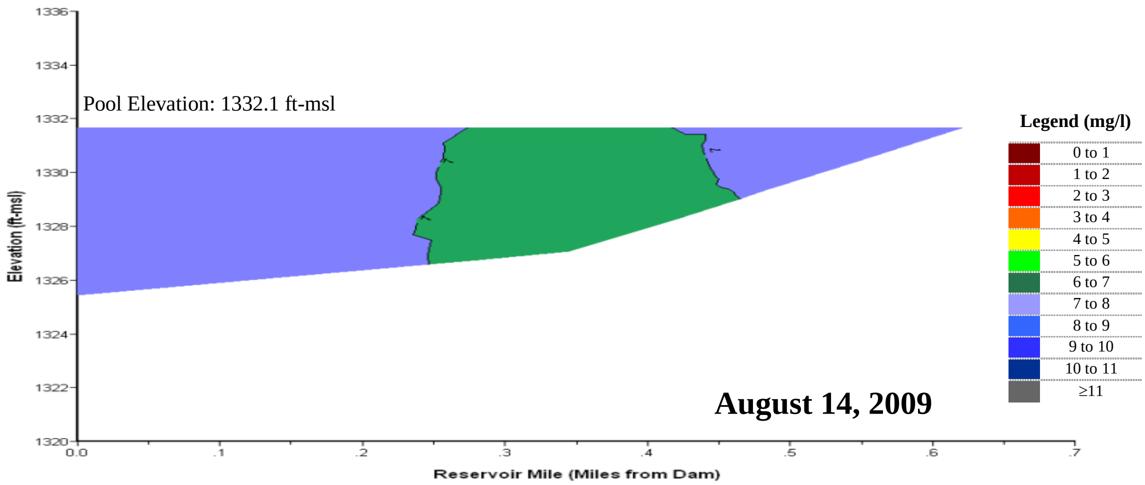


Plate 148. Longitudinal dissolved oxygen (mg/l) contour plots of Olive Creek Reservoir based on depth-profile dissolved oxygen concentrations measured at sites OCRLKND1 and OCRLKML1 in 2009.



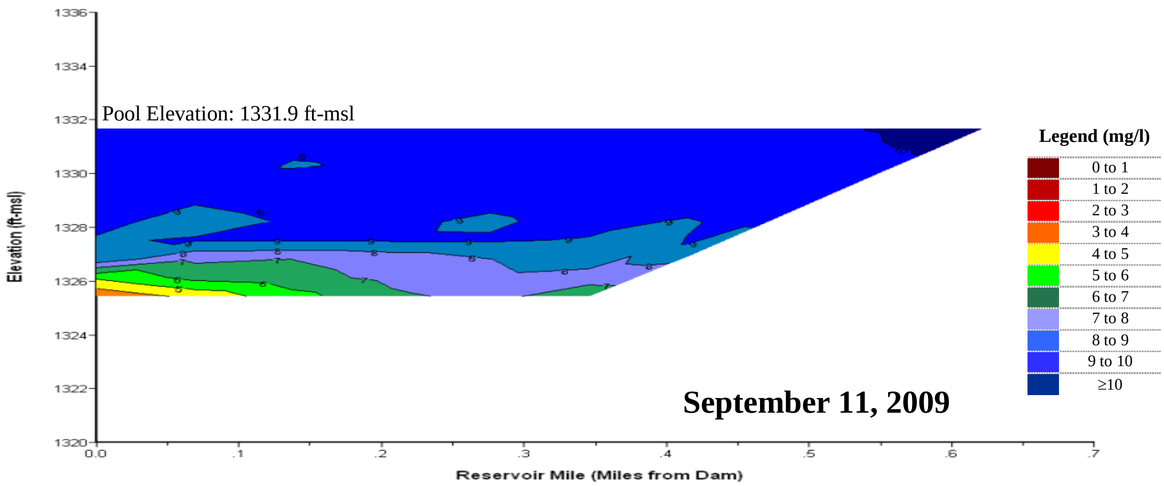


Plate 148. (Continued).

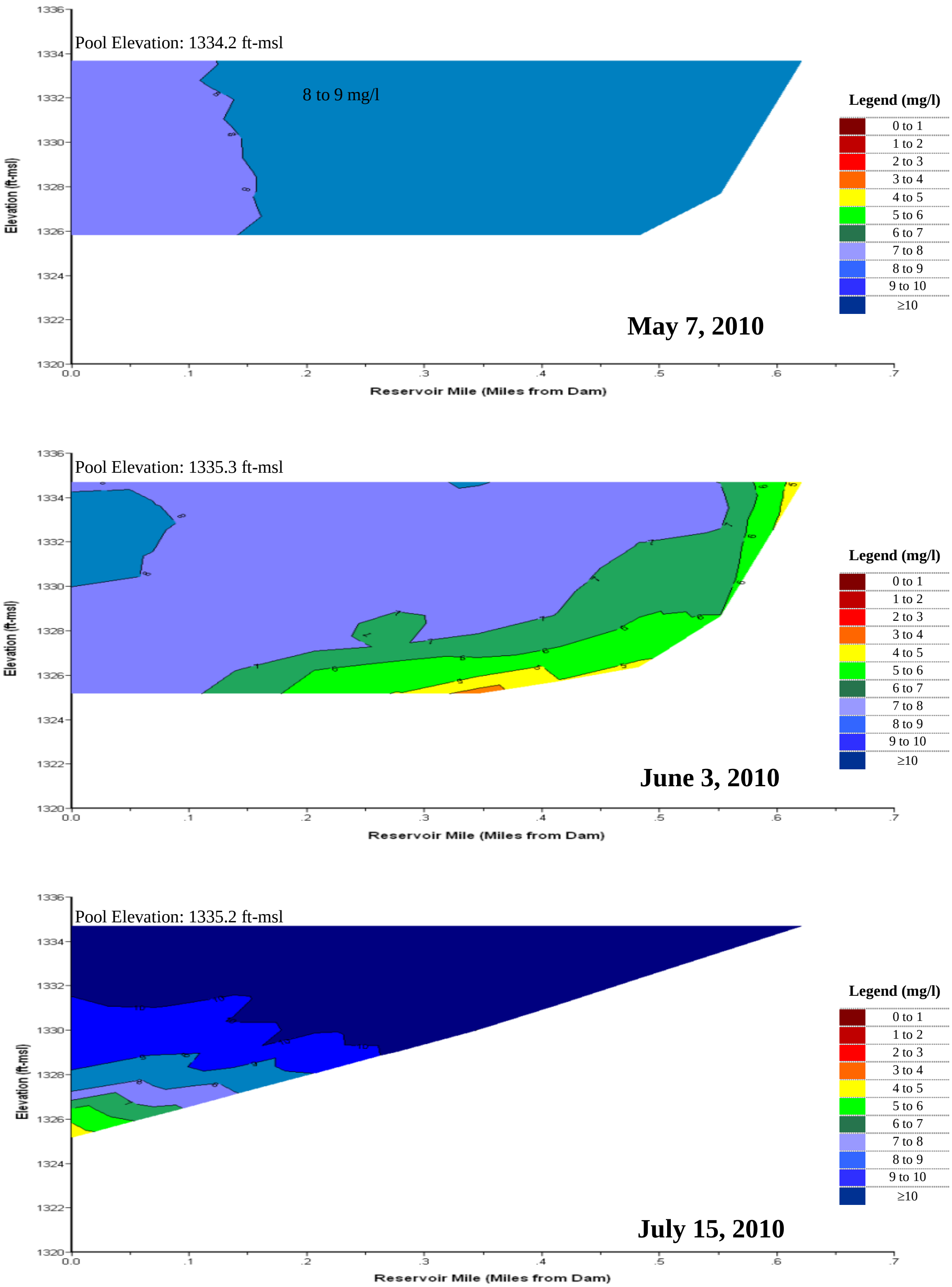
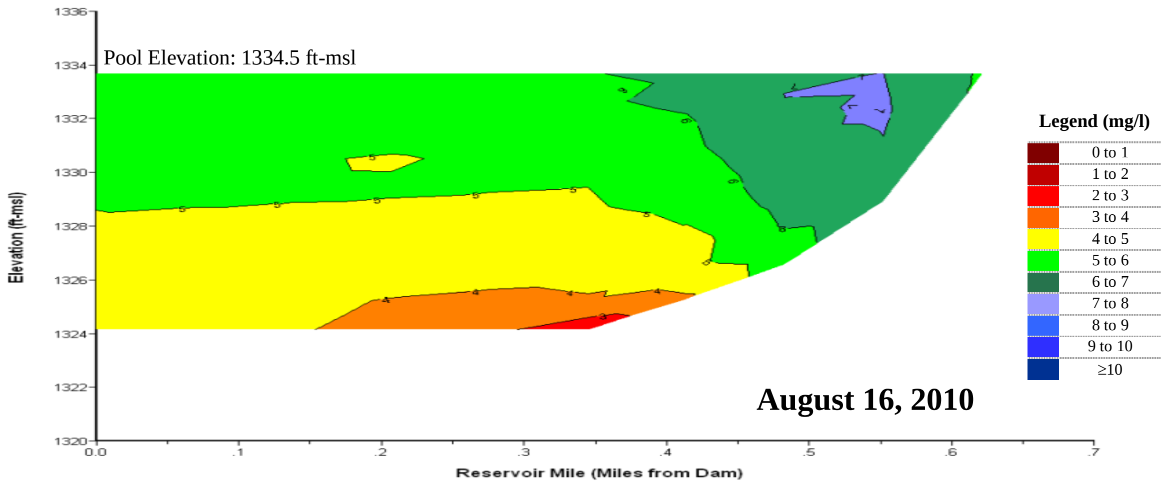


Plate 149. Longitudinal dissolved oxygen (mg/l) contour plots of Olive Creek based on depth-profile dissolved oxygen concentrations measured at sites OCRLKND1, OCRLKML1, and OCRLKUP1 in 2010.



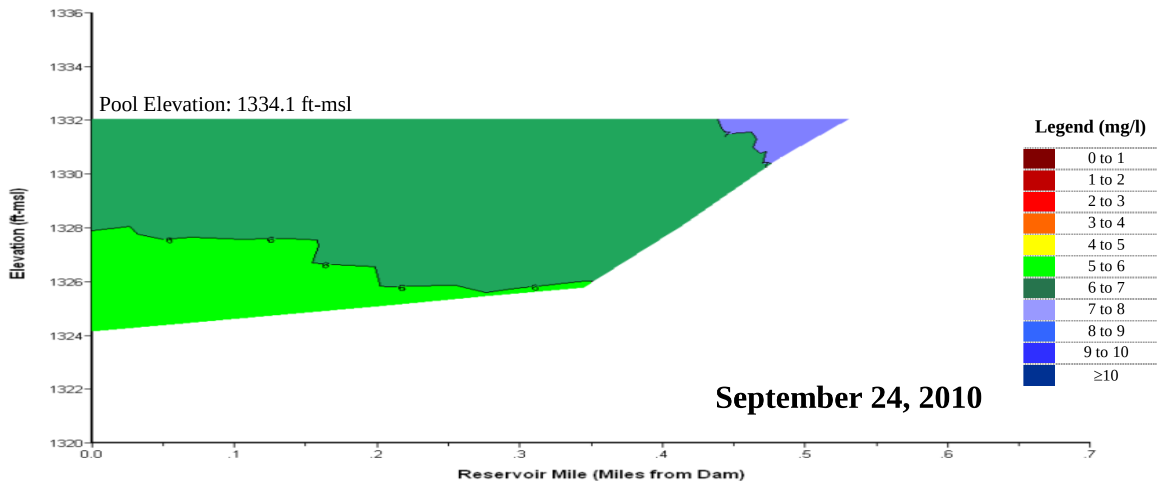


Plate 149. (Continued).

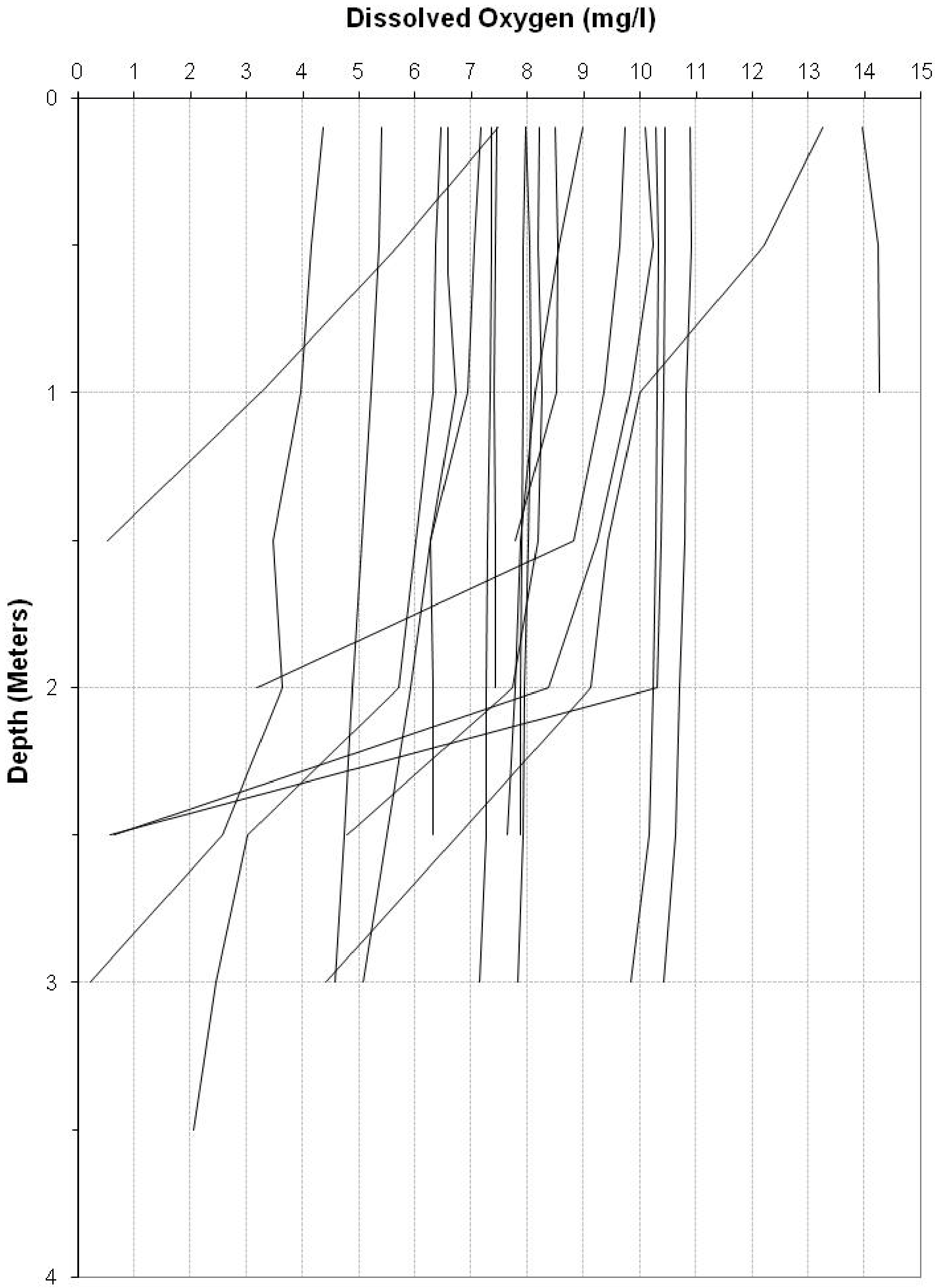


Plate 150. Dissolved Oxygen depth profiles for Olive Creek Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., OCRLKND1) during the summer over the 5-year period of 2006 through 2010.

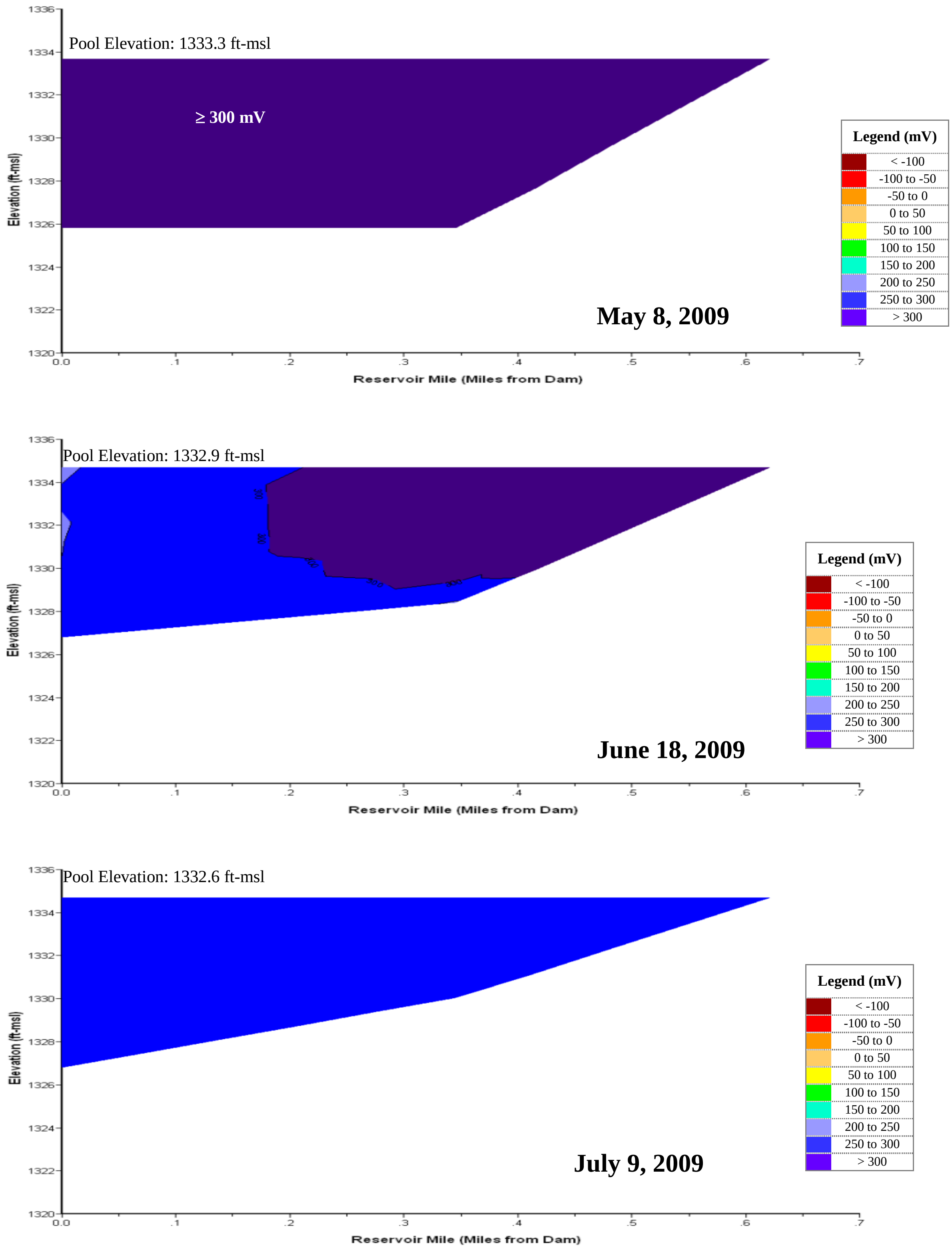
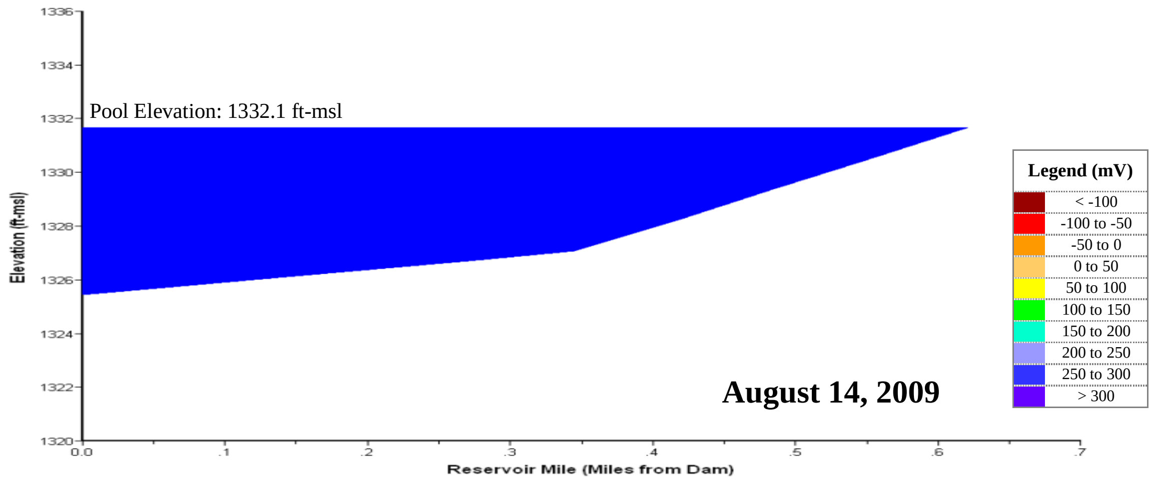


Plate 151. Longitudinal oxidation-reduction potential (mV) contour plots of Olive Creek Reservoir based on depth-profile OR levels measured at sites OCRLKND1 and OCRLKML1 in 2009.



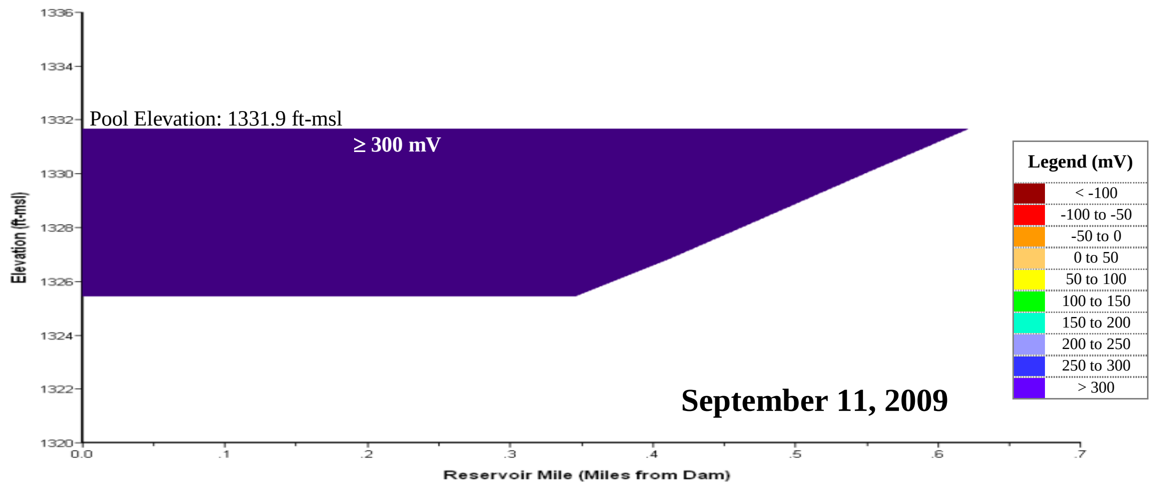


Plate 151. (Continued).

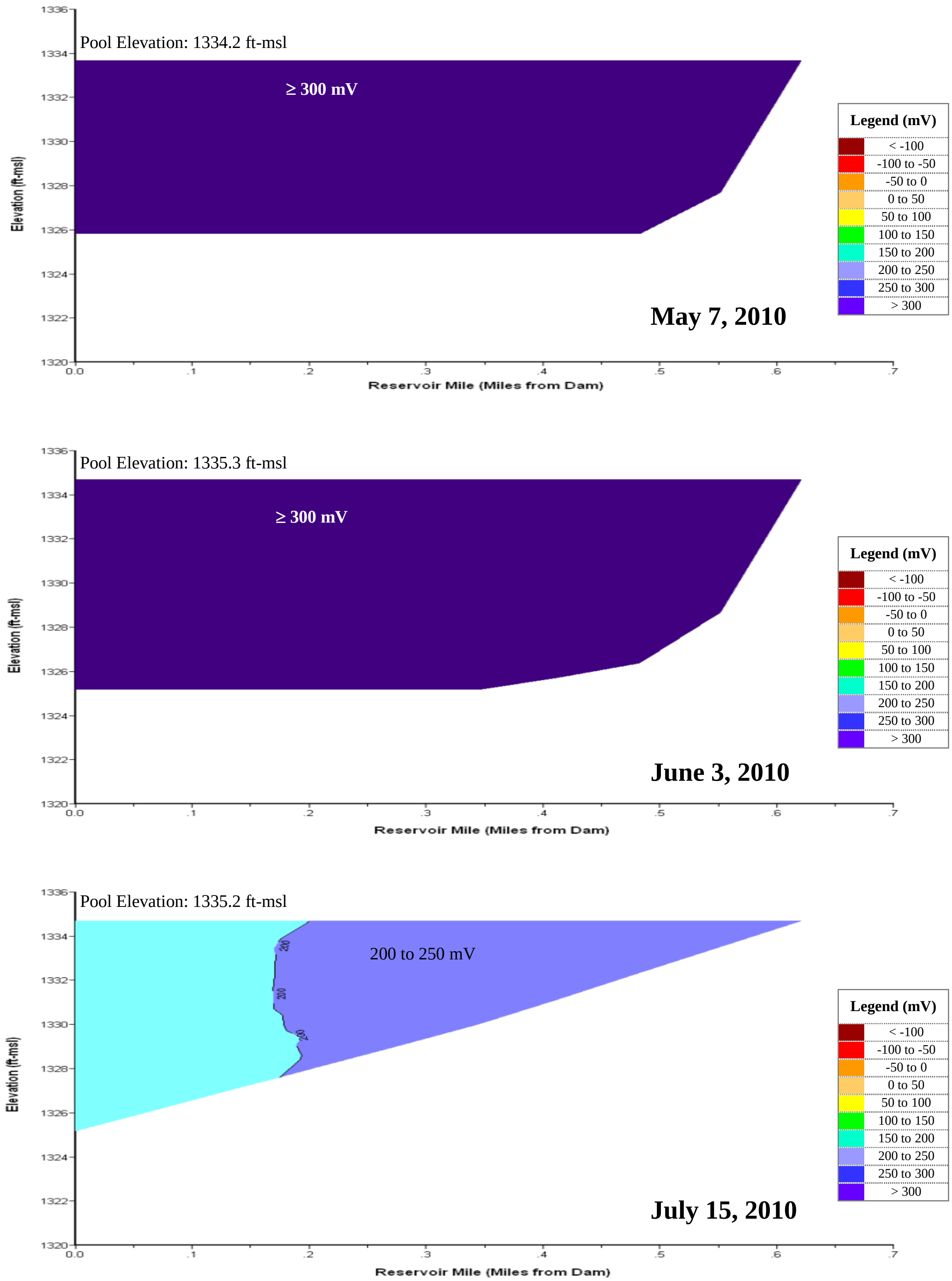
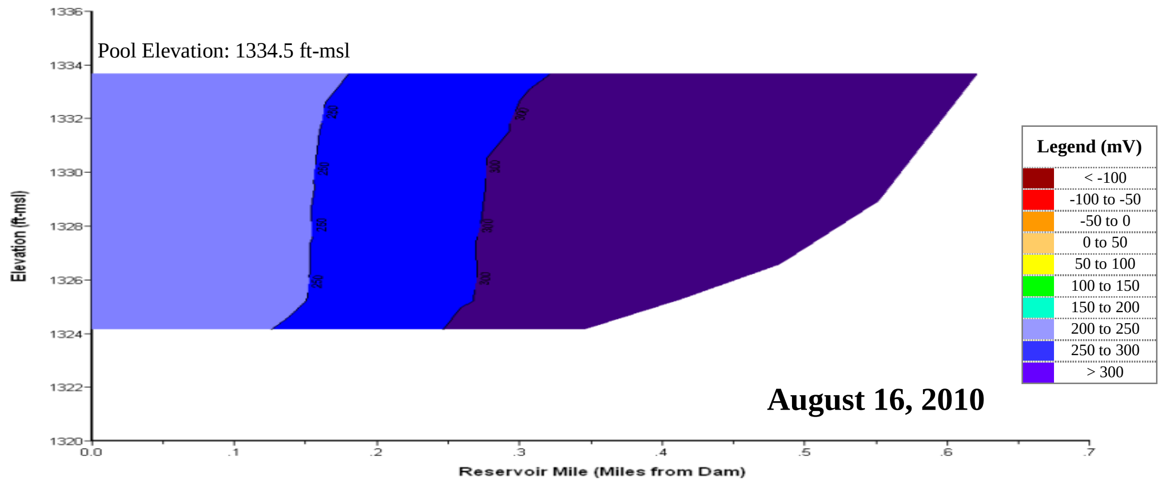


Plate 152. Longitudinal oxidation-reduction potential (mV) contour plots of Olive Creek based on depth-profile ORP levels measured at sites OCRLKND1, OCRLKML1, and OCRLKUP1 in 2010.



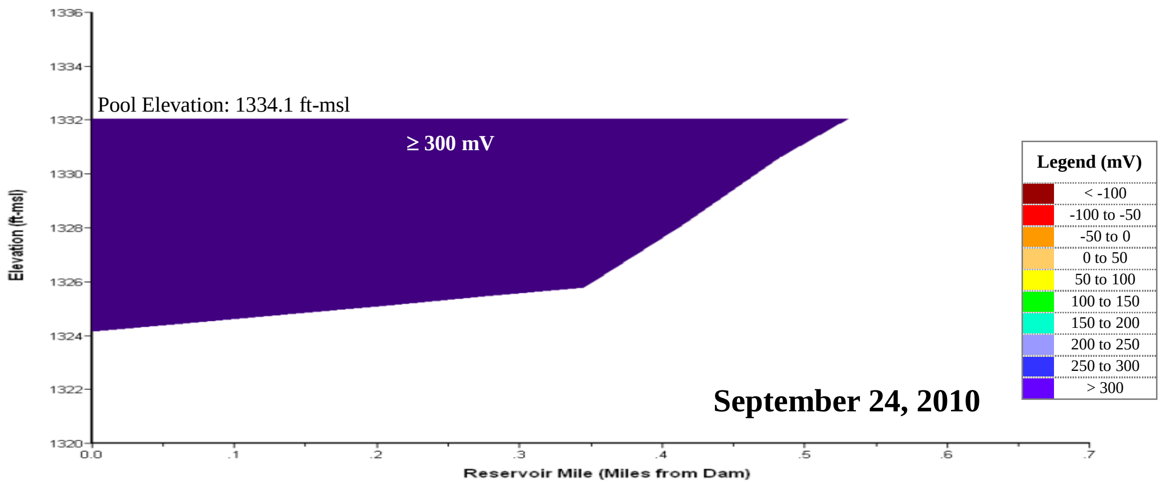


Plate 152. (Continued).

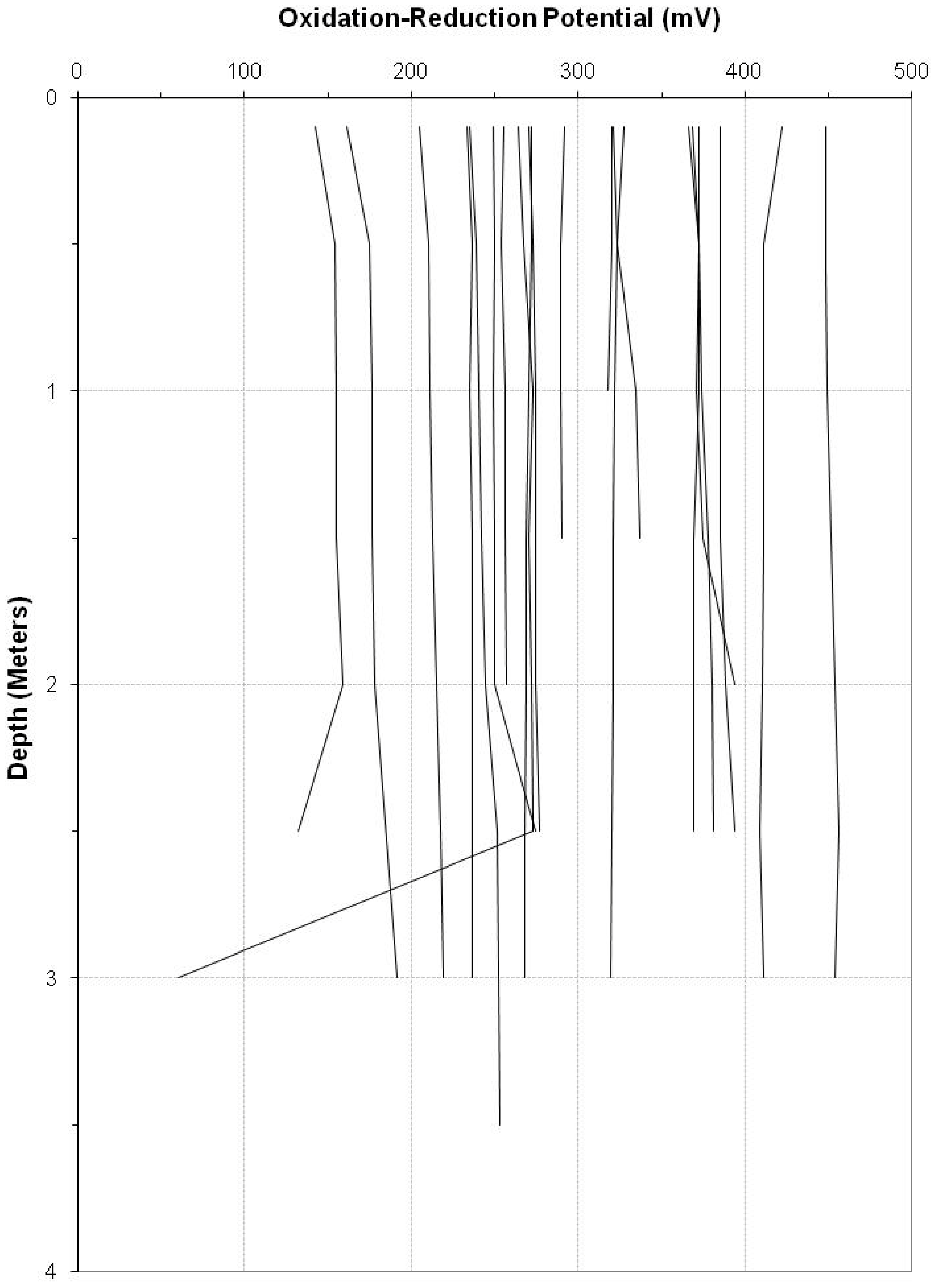
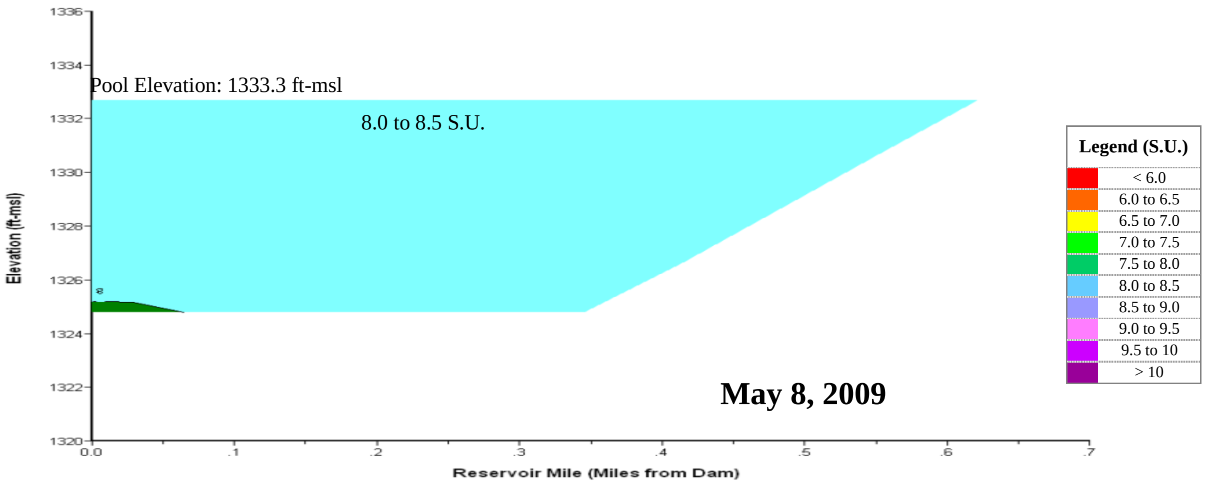
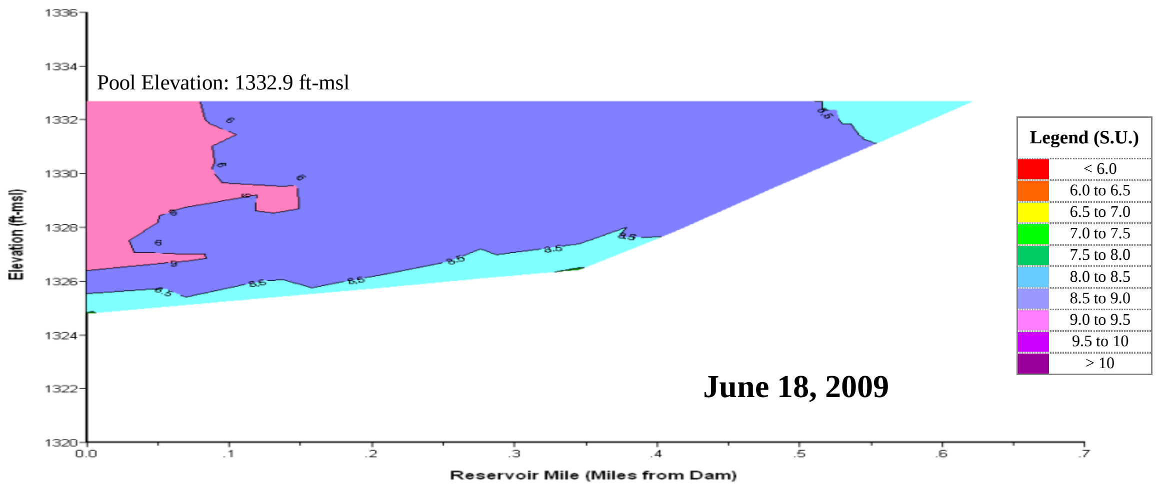


Plate 153. Oxidation-reduction potential depth profiles for Olive Creek Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., OCRLKND1) during the summer over the 5-year period of 2006 through 2010.





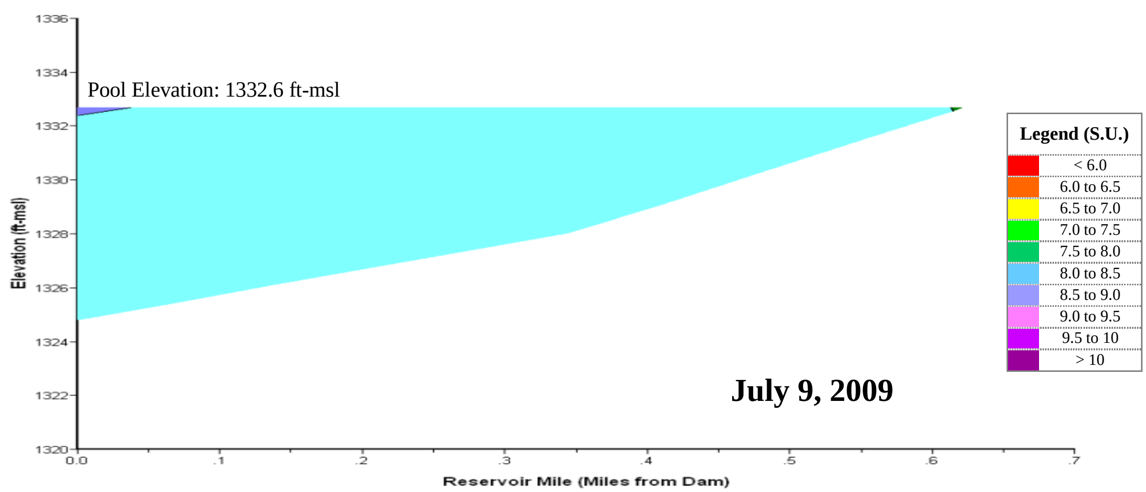
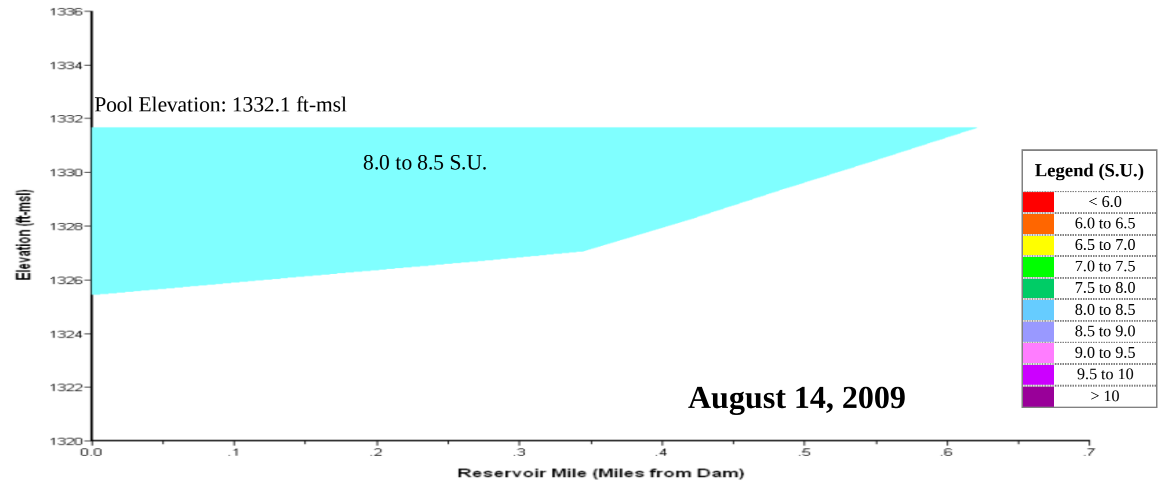


Plate 154. Longitudinal pH (S.U.) contour plots of Olive Creek Reservoir based on depth-profile pH levels measured at sites OCRLKND1 and OCRLKML1 in 2009.



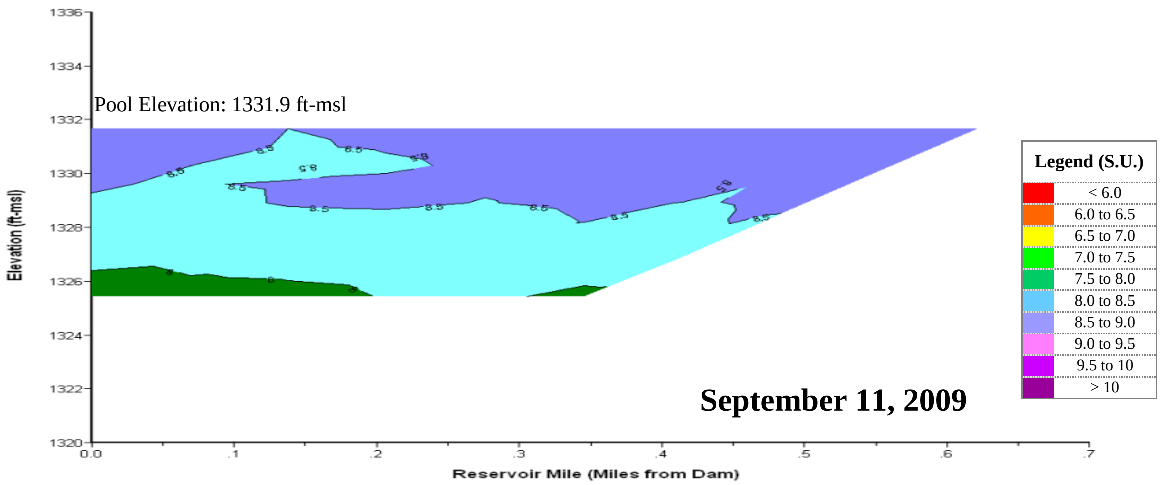
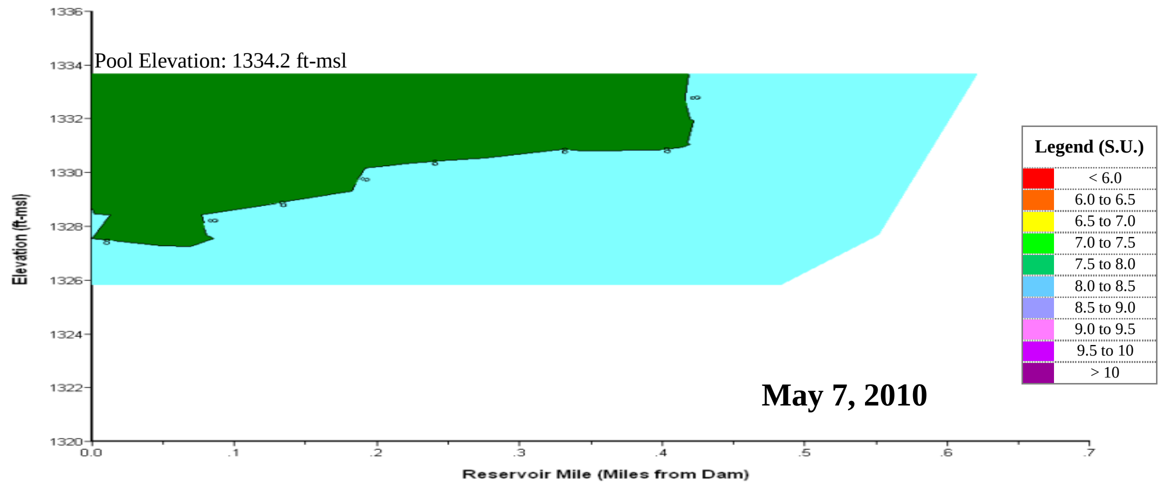
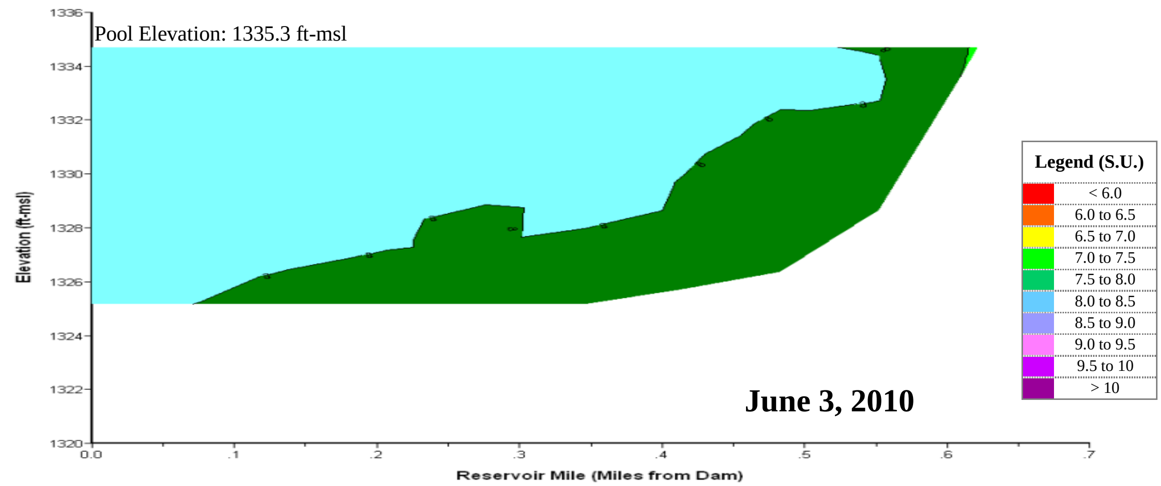


Plate 154. (Continued).





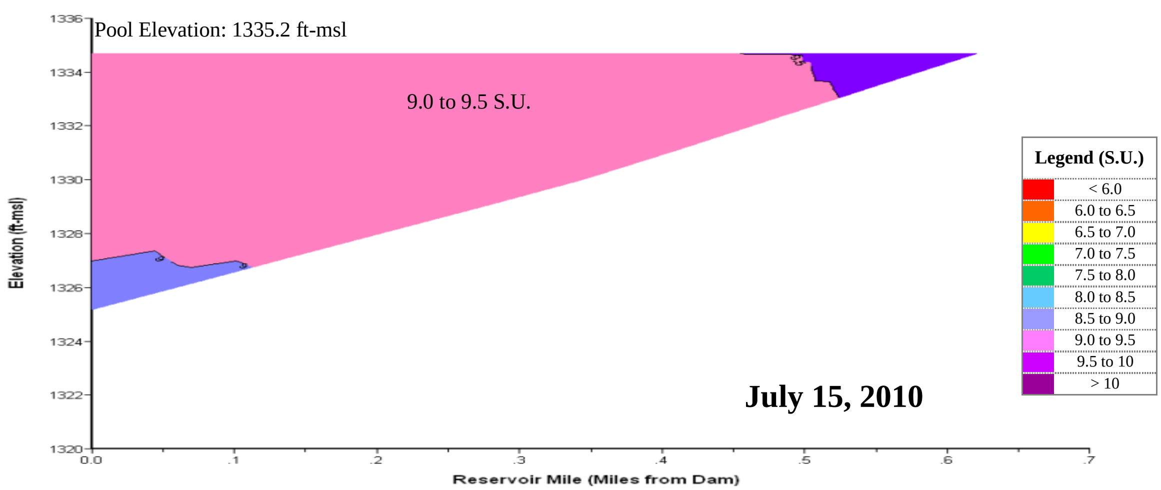
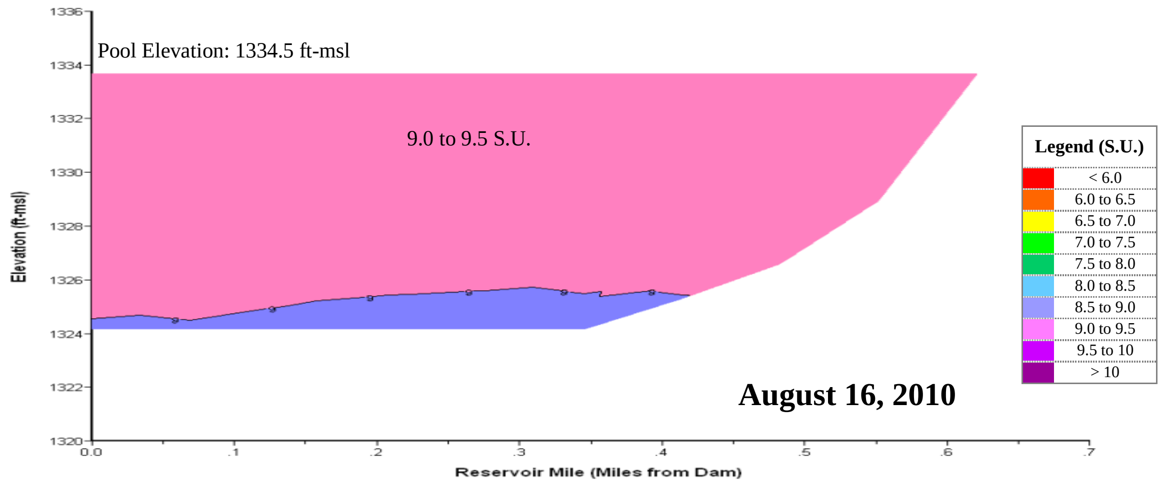


Plate 155. Longitudinal pH (S.U.) contour plots of Olive Creek based on depth-profile pH levels measured at sites OCRLKND1, OCRLKML1, and OCRLKUP1 in 2010.



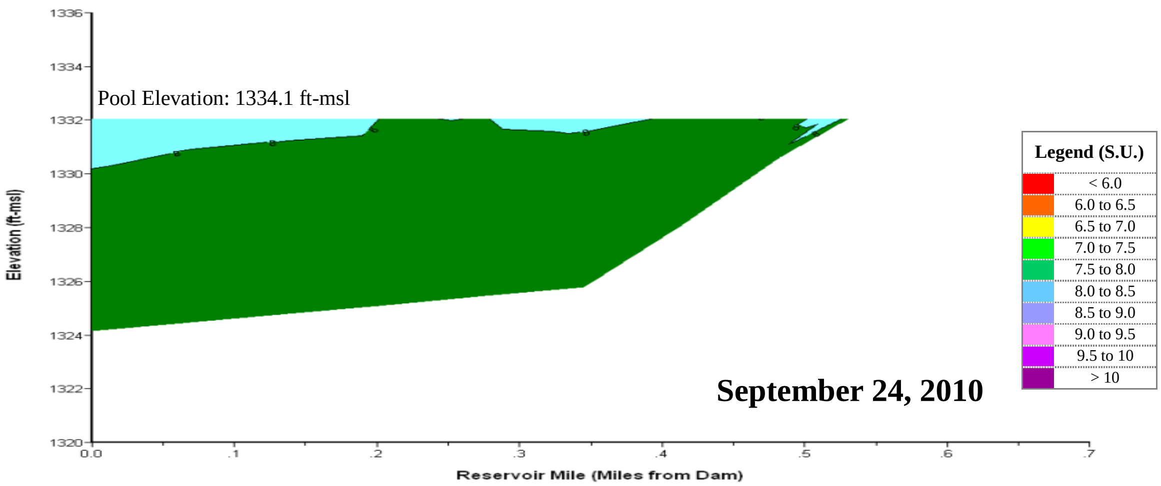


Plate 155. (Continued).

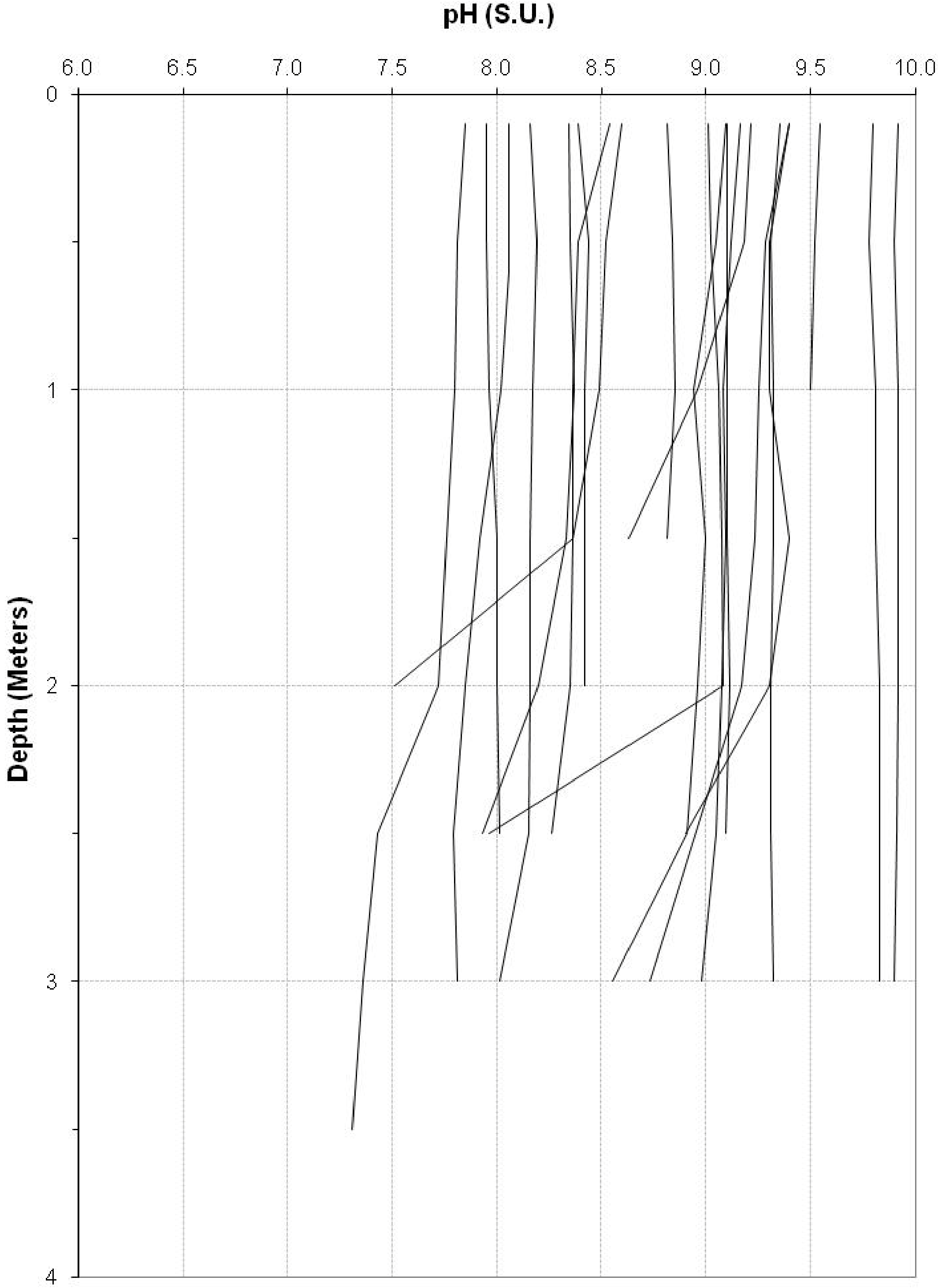


Plate 156. pH depth profiles for Olive Creek Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., OCRLKND1) during the summer over the 5-year period of 2006 through 2010.

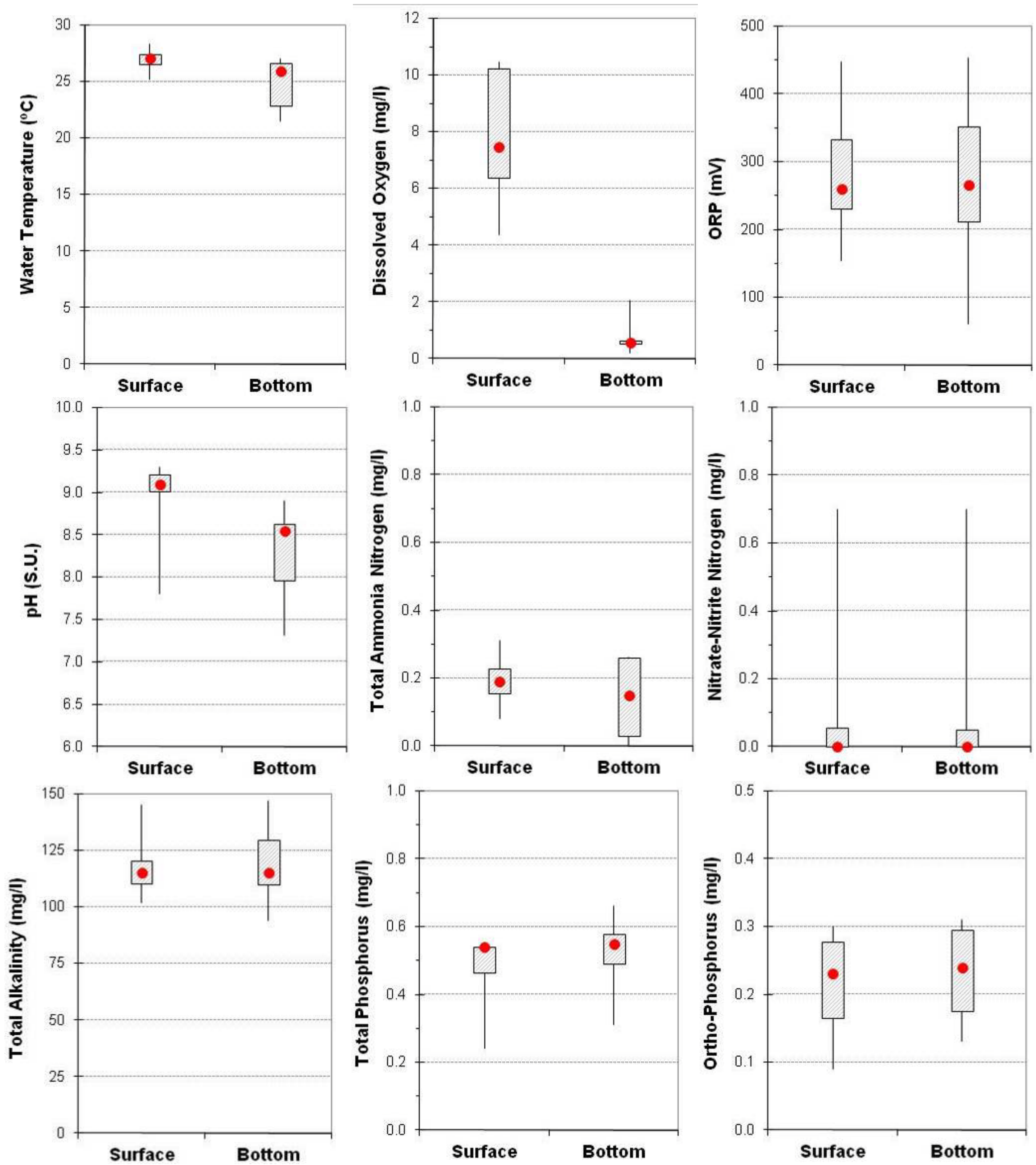


Plate 157. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, alkalinity, total ammonia nitrogen, nitrate-nitrite nitrogen, total phosphorus, and ortho-phosphorus measured in Olive Creek Reservoir when summer hypoxic conditions were present during the 5-year period 2006 through 2010. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

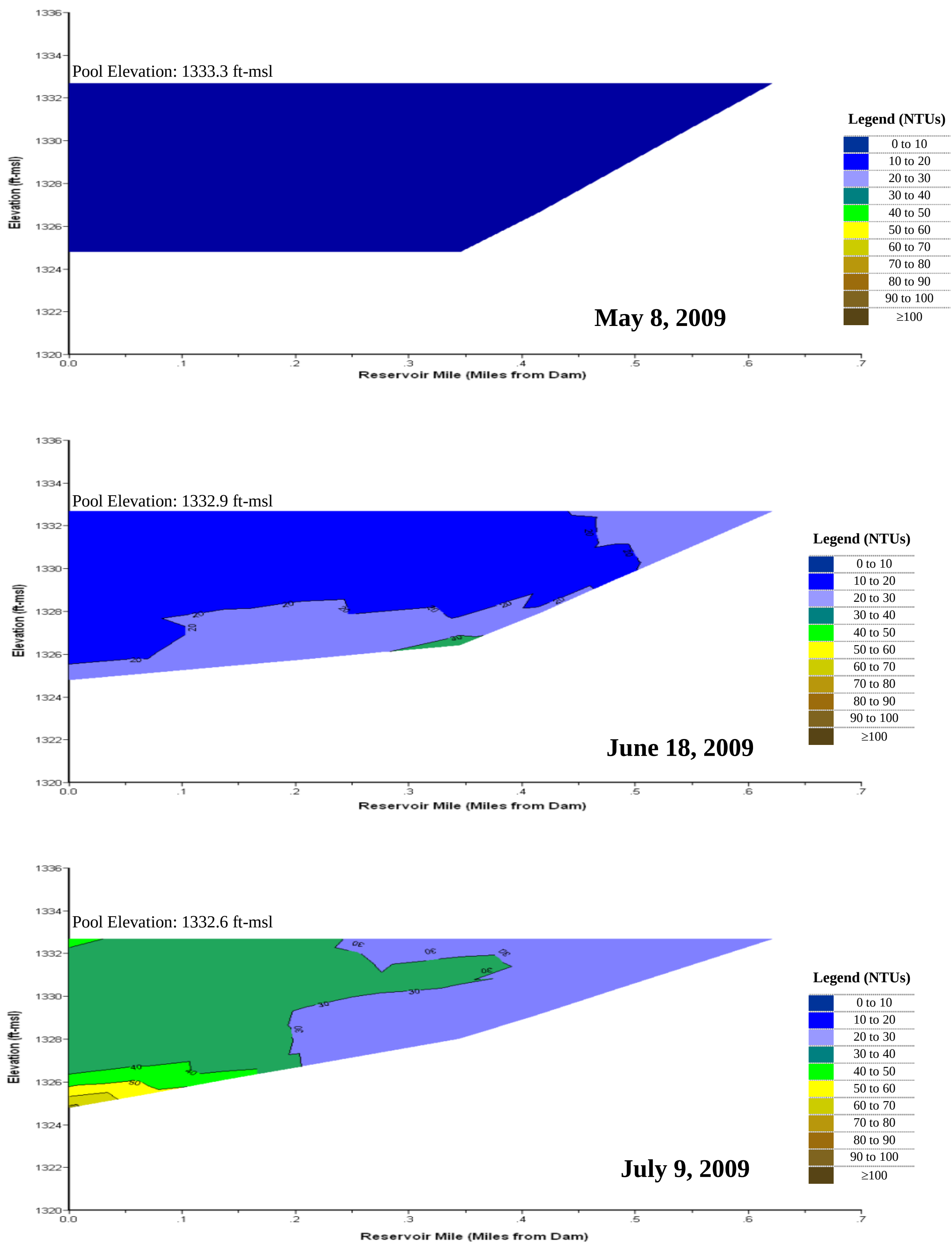
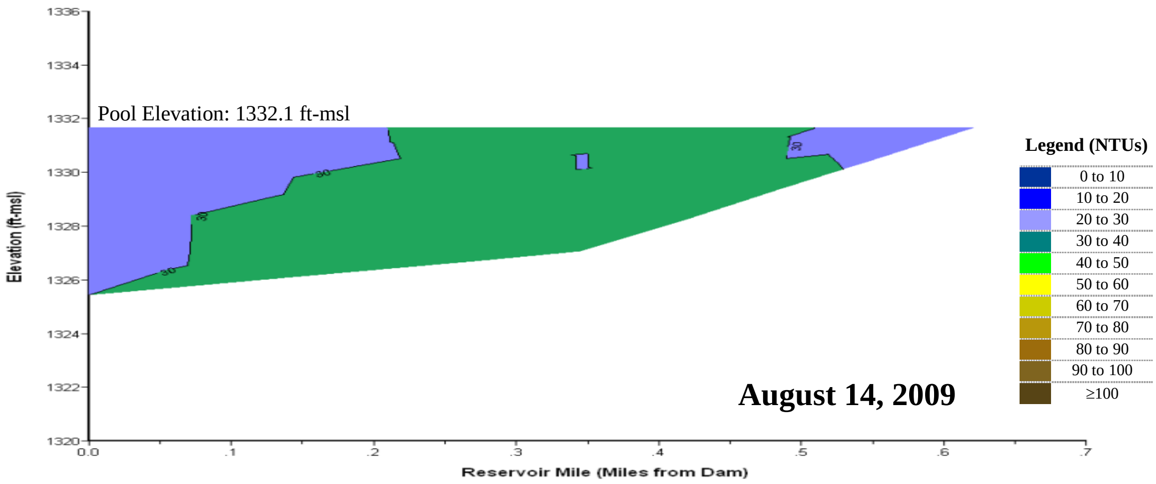


Plate 158. Longitudinal turbidity (NTU) contour plots of Olive Creek Reservoir based on depth-profile turbidity levels measured at sites OCRLKND1 and OCRLKML1 in 2009.



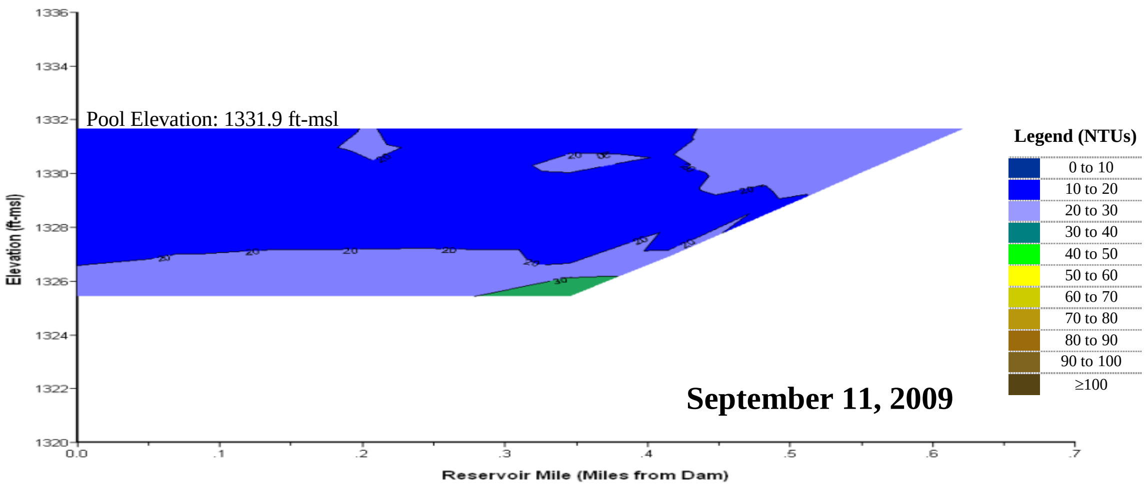


Plate 158. (Continued).

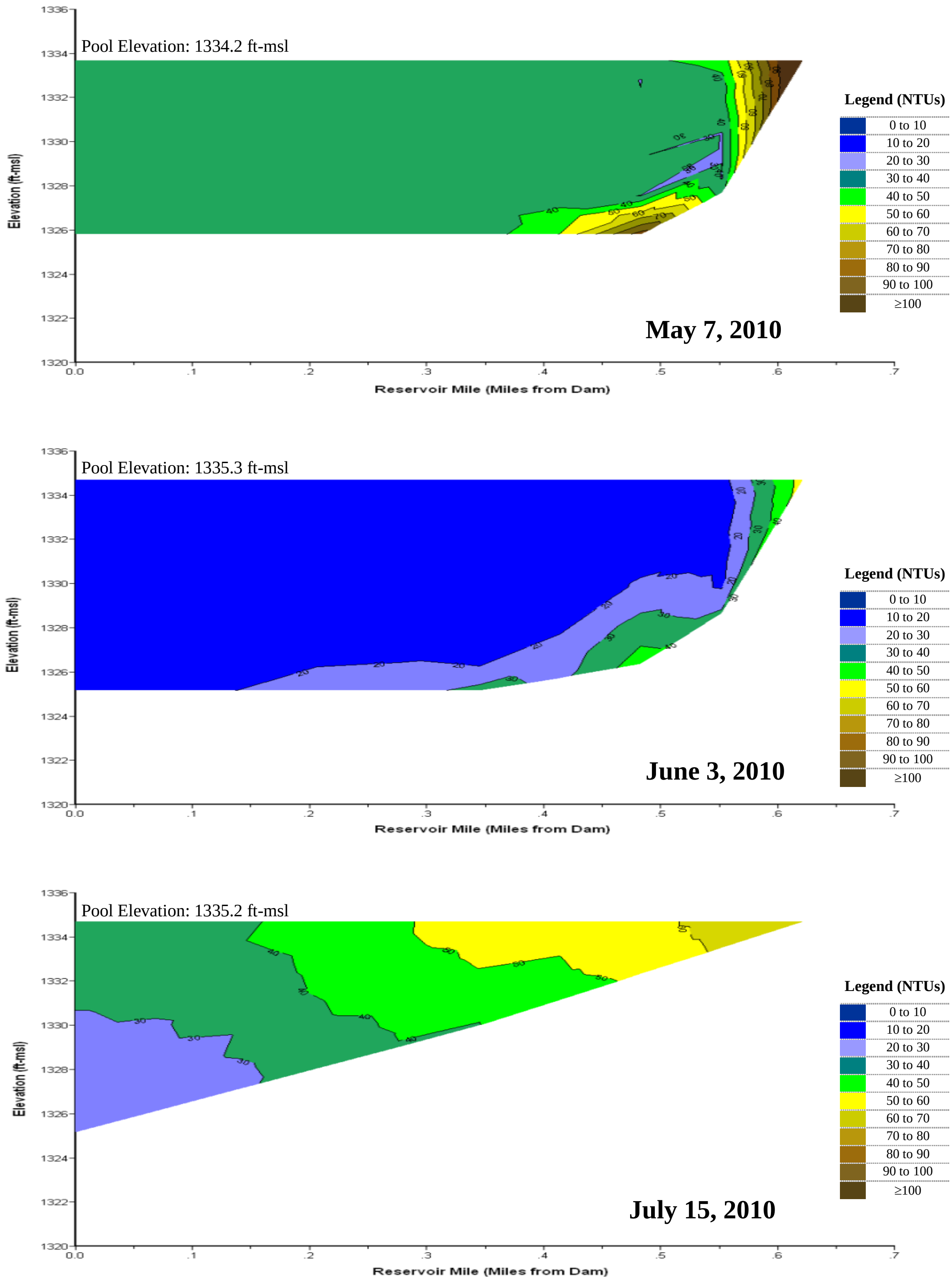
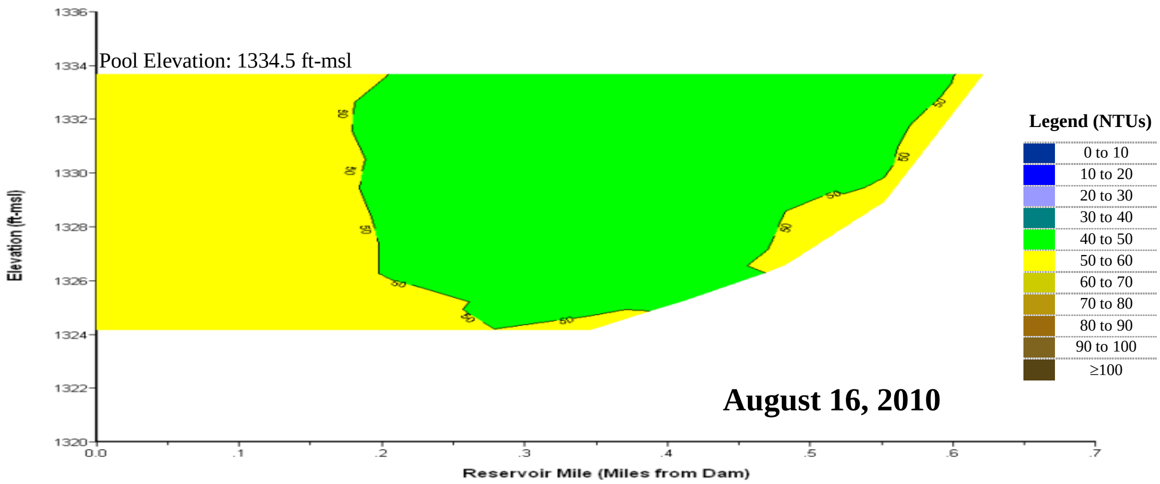


Plate 159. Longitudinal turbidity (NTU) contour plots of Olive Creek based on depth-profile turbidity levels measured at sites OCRLKND1, OCRLKML1, and OCRLKUP1 in 2010.



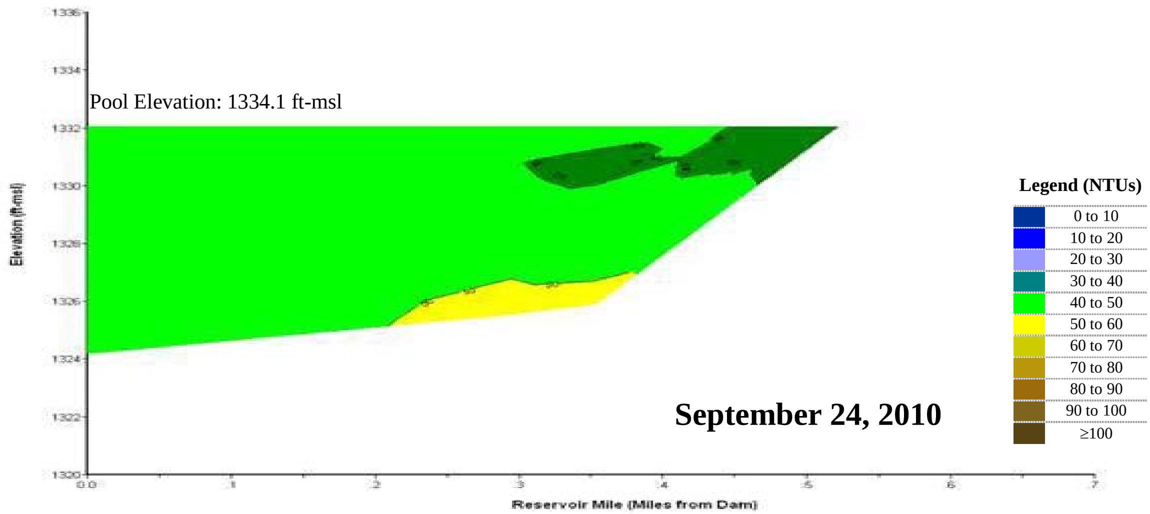


Plate 159. (Continued).

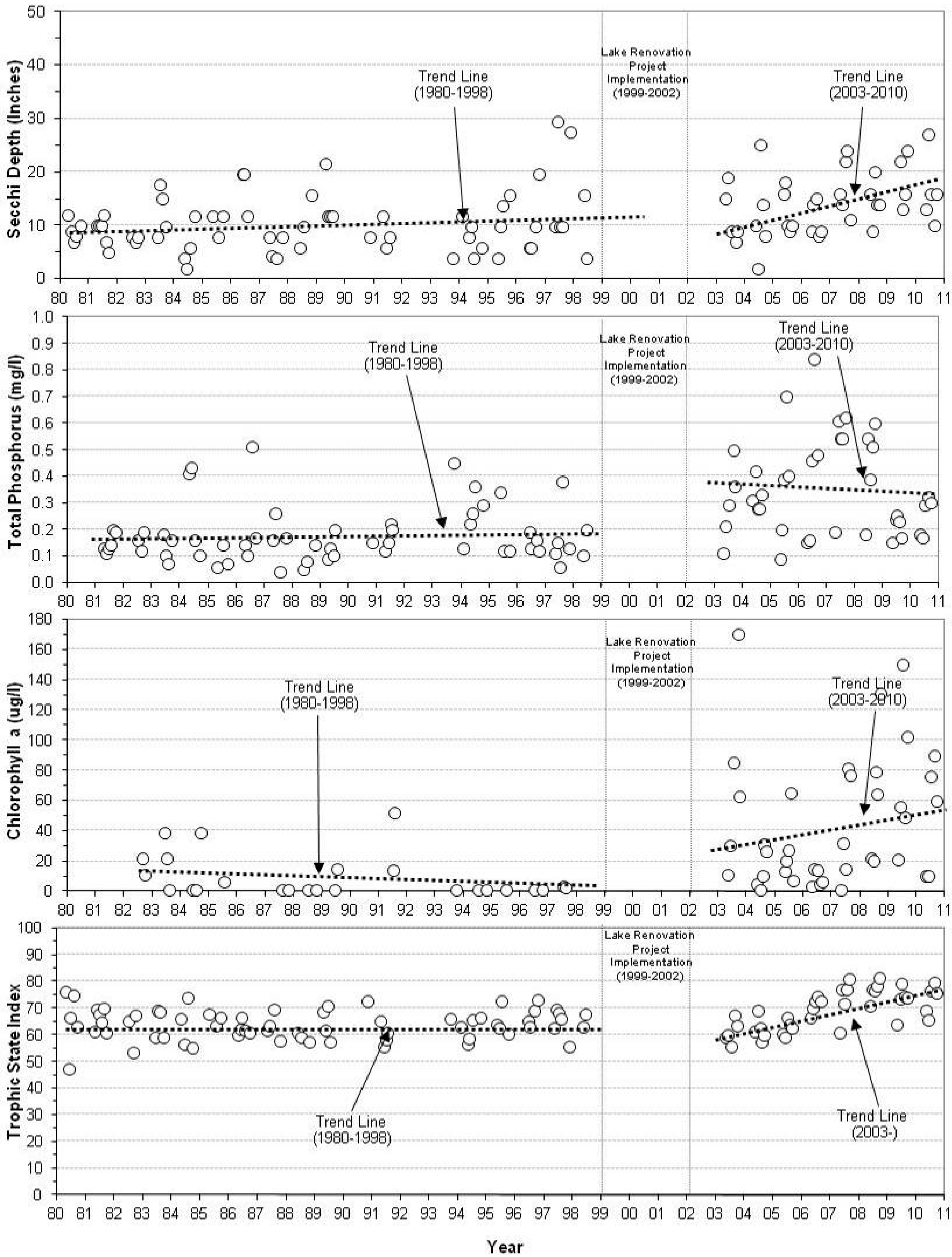


Plate 160. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Olive Creek Reservoir at the near-dam, ambient site (i.e., site OCRLKND1) over the 31year period of 1980 through 2010. (Note: lake renovation project implemented from 1999 through 2002).

Plate 161. Summary of runoff water quality conditions monitored in the main west tributary inflow to Olive Creek Reservoir at monitoring site OCRNFWST1 during the 5-year period 2004 through 2008**.** Runoff conditions have not been monitored since 2008.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Kjeldahl N, Total (mg/l)	0.1	7	3.7	3.3	2.5	5.2	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	7	4.08	2.90	1.10	7.68	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	7	1.00	0.90	0.71	1.30	-----	-----	-----
Suspended Solids, Total (mg/l)	4	7	501	470	220	1,030	-----	-----	-----
Acetochlor, Total (ug/l)[C]	0.05	6	11.23	3.66	0.28	46.50	-----	-----	-----
Atrazine, Total (ug/l)[C]	0.05	7	10.79	6.05	0.55	25.10	330[1], 12[2]	0, 6	0, 43%
Metolachlor, Total (ug/l)[C]	0.05	6	6.47	2.90	2.20	24.50	390[1], 100[2]	0	0%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Acute criterion for aquatic life.
(2) Chronic criterion for aquatic life.
(C) Immunoassay analysis.

Plate 162. Summary of runoff water quality conditions monitored in the main east tributary inflow to Olive Creek Reservoir at monitoring site OCRNFEST1 during the 5-year period 2004 through 2008**.** Runoff conditions have not been monitored since 2008.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Kjeldahl N, Total (mg/l)	0.1	7	3.27	3.30	1.30	4.40	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	7	4.44	3.30	2.10	9.52	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	7	1.04	1.06	0.79	1.55	-----	-----	-----
Suspended Solids, Total (mg/l)	4	7	459	520	146	700	-----	-----	-----
Acetochlor, Total (ug/l)[C]	0.05	6	6.99	5.79	1.21	18.50	-----	-----	-----
Atrazine, Total (ug/l)[C]	0.05	7	20.83	17.16	0.63	56.20	330[1], 12[2]	0, 4	0%, 57%
Metolachlor, Total (ug/l)[C]	0.05	7	4.24	3.73	1.71	10.00	390[1], 100[2]	0	0%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Acute criterion for aquatic life.
(2) Chronic criterion for aquatic life.
(C) Immunoassay analysis.

Plate 163. Summary of water quality conditions monitored in Pawnee Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site PAWLKND1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[A]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	26	1243.8	1244.1	1241.6	1245.8	-----	-----	-----
Water Temperature (°C)	0.1	304	22.8	23.3	14.4	30.6	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	305	6.7	7.4	0.2	13.0	≥ 5[2]	56	18%
Dissolved Oxygen (% Sat.)	0.1	294	80.0	87.5	2.1	155.7	-----	-----	-----
Specific Conductance (umho/cm)	1	293	371	373	268	477	2,000[3]	0	0%
pH (S.U.)	0.1	293	8.4	8.4	6.9	9.6	≥6.5 & ≤9.0[1]	24	8%
Turbidity (NTUs)	1	293	23	19	4	207	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	293	310	332	-101	466	-----	-----	-----
Secchi Depth (in.)	1	26	25	25	14	45	-----	-----	-----
Alkalinity, Total (mg/l)	7	50	154	152	102	200	20[1]	0	0%
Ammonia, Total (mg/l)	0.01	50	-----	0.16	0.00	1.17	2.65[4,5], 0.52[4,6]	0, 2	0%, 4%*
Chlorophyll *a* (ug/l) – Field Probe	1	245	30	18	1	154	10[7]	144	59%
Chlorophyll *a* (ug/l) – Lab Determined	1	25	39	41	1	113	10[7]	20	80%
Hardness, Total (mg/l)	0.4	5	124.0	125.0	104.0	141.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.10	50	1.6	1.6	0.8	3.1	-----	-----	-----
Nitrogen, Total (mg/)	0.10	50	1.7	1.6	0.8	3.1	1[7]	46	92%
Nitrate-Nitrite N, Total (mg/l)	0.02	50	-----	n.d.	n.d.	0.60	100[3]	0	0%
Phosphorus, Total (mg/l)	0.10	50	0.1	0.1	n.d.	0.6	0.05[7]	46	92%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	-----	0.04	n.d.	0.28	-----	-----	-----
Suspended Solids, Total (mg/l)	4	50	14	13	n.d.	43	-----	-----	-----
Aluminum, Dissolved (ug/l)	25	5	-----	n.d.	n.d.	35	750[5], 87[6]	0	0%
Antimony, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	1	88[5], 30[6]	0	0%
Arsenic, Dissolved (ug/l)	3	5	-----	n.d.	n.d.	10	340[5], 16.7[8]	0	0%
Beryllium, Dissolved (ug/l)	3	5	-----	n.d.	n.d.	n.d.	130[5], 5.3[6]	0	0%
Cadmium, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	7.3[5], 0.3[6]	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	3	710[5], 93[6]	0	0%
Copper, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	3	17[5], 11[6]	0	0%
Lead, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	82[5], 3.2[6]	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4[5]	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77[6]	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	566[5], 63[6]	0	0%
Selenium, Total (ug/l)	2	5	-----	n.d.	n.d.	10	20[3,5], 5[6]	0, 1	0%, 20%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	5.1[5]	0	0%
Thallium (ug/l)	3	5	-----	n.d.	n.d.	n.d.	1,400[5], 6.3[8]	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	142[5,6]	0	0%
Microcystin, Total (ug/l)	0.05	24	-----	n.d.	n.d.	5.10	20[9]	0	0%
Acetochlor, Total (ug/l)[C]	0.05	9	0.19	0.20	n.d.	0.42	-----	-----	-----
Alachlor, Total (ug/l)[C]	0.05	15	0.54	0.40	0.10	2.20	760[5], 76[6]	0	0%
Atrazine, Total (ug/l)[C]	0.05	24	1.30	1.00	0.30	4.90	330[5], 12[6]	0	0%
Metolachlor, Total (ug/l)[C]	0.05	24	0.32	0.20	n.d.	1.50	390[5], 100[6]	0	0%
Pesticide Scan (ug/l)[D]	0.05						-----	-----	-----
Atrazine		5	-----	0.50	n.d.	1.30	330[5], 12[6]	0	0%
Deethylatrazine		4	-----	0.15	n.d.	0.30	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l microcystins in recreation water for impairment assessment.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 164. Summary of water quality conditions monitored in Pawnee Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site PAWLKML1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, and ORP are for water column depth-profile measurements.]

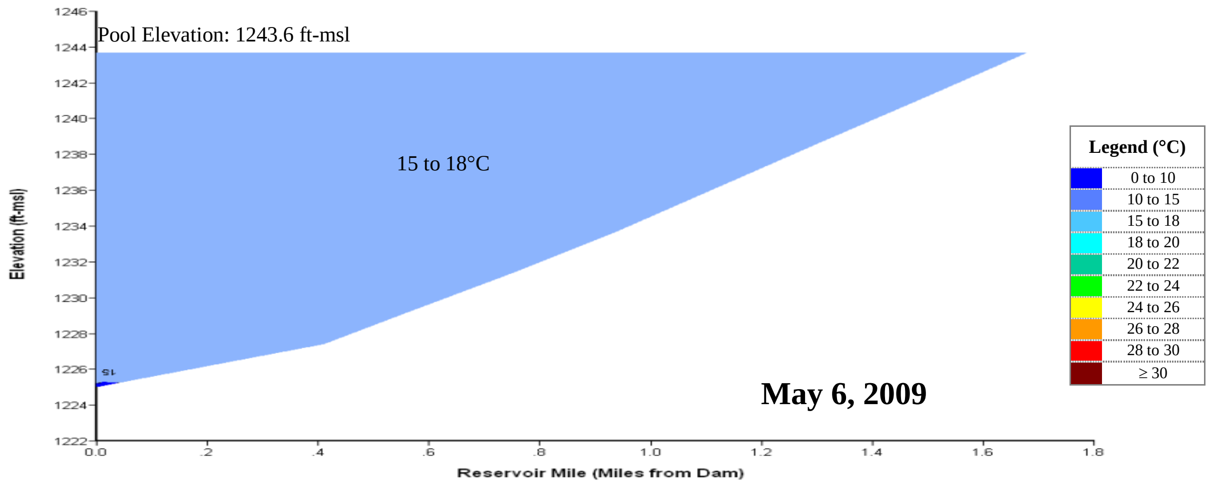
Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[(A)]	Median	Min.	Max.	State WQS Criteria[(B)]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	24	1243.8	1244.2	1241.6	1245.8	-----	-----	-----
Water Temperature (°C)	0.1	213	23.0	23.3	15.0	30.8	32[(1)]	0	0%
Dissolved Oxygen (mg/l)	0.1	213	8.0	7.9	0.5	12.7	≥ 5[(2)]	8	4%
Dissolved Oxygen (% Sat.)	0.1	203	97.2	95.4	6.2	167.4	-----	-----	-----
Specific Conductance (umho/cm)	1	203	369	370	268	431	2,000[(3)]	0	0%
pH (S.U.)	0.1	203	8.5	8.5	7.4	9.6	≥6.5 & ≤9.0[(1)]	25	12%*
Turbidity (NTUs)	1	202	28	25	5	99	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	203	328	343	134	494	-----	-----	-----
Secchi Depth (in.)	1	25	21	19	11	42	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	166	37	19	1	197	10[(4)]	112	67%

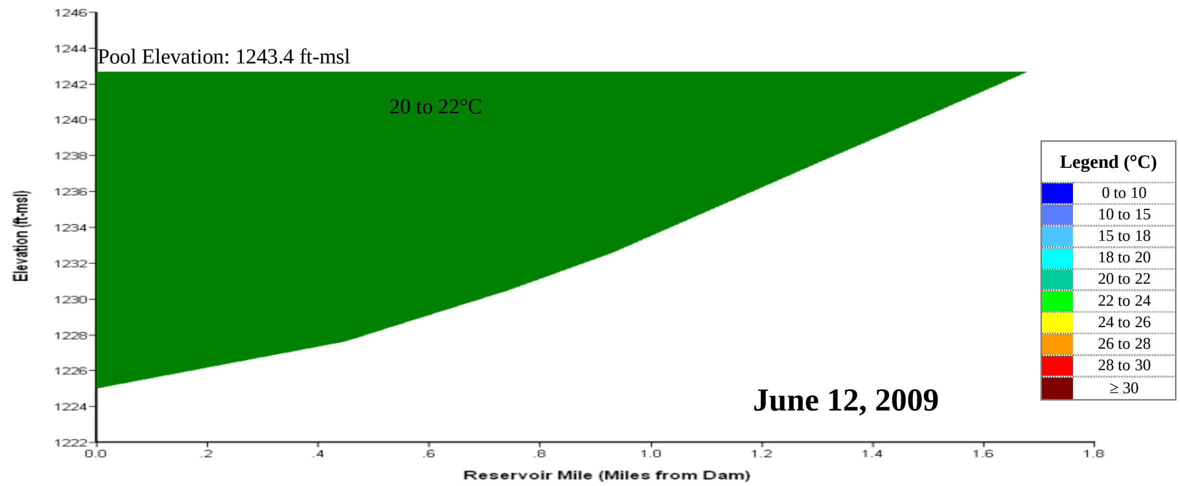
n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.





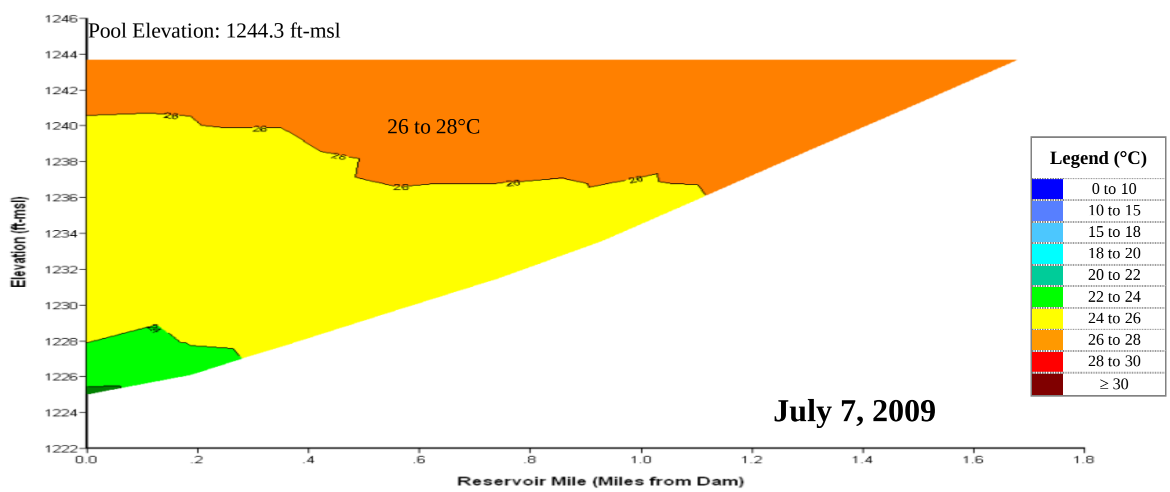
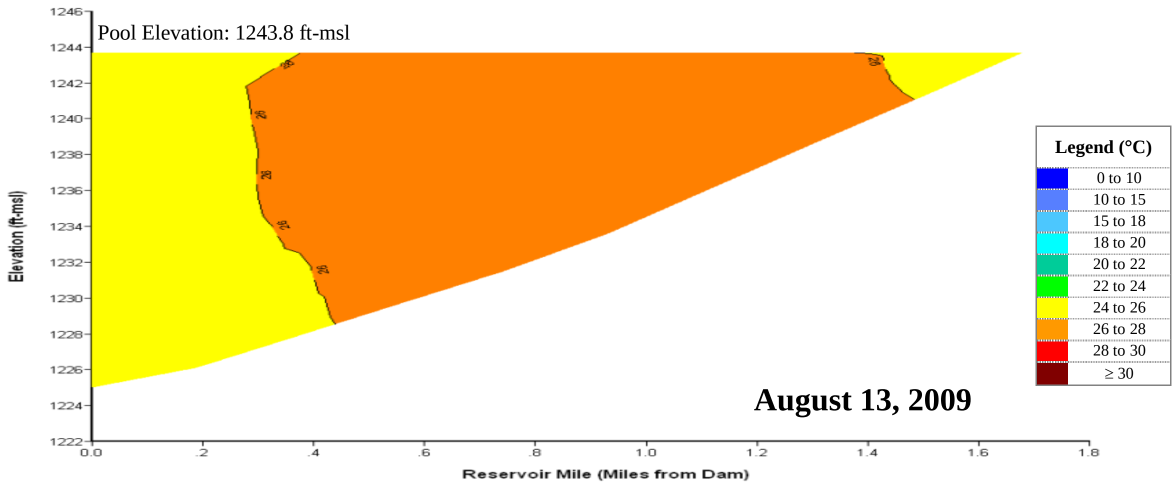


Plate 165. Longitudinal water temperature (°C) contour plots of Pawnee Reservoir based on depth-profile water temperatures measured at sites PAWLKND1 and PAWLKML1 in 2009.



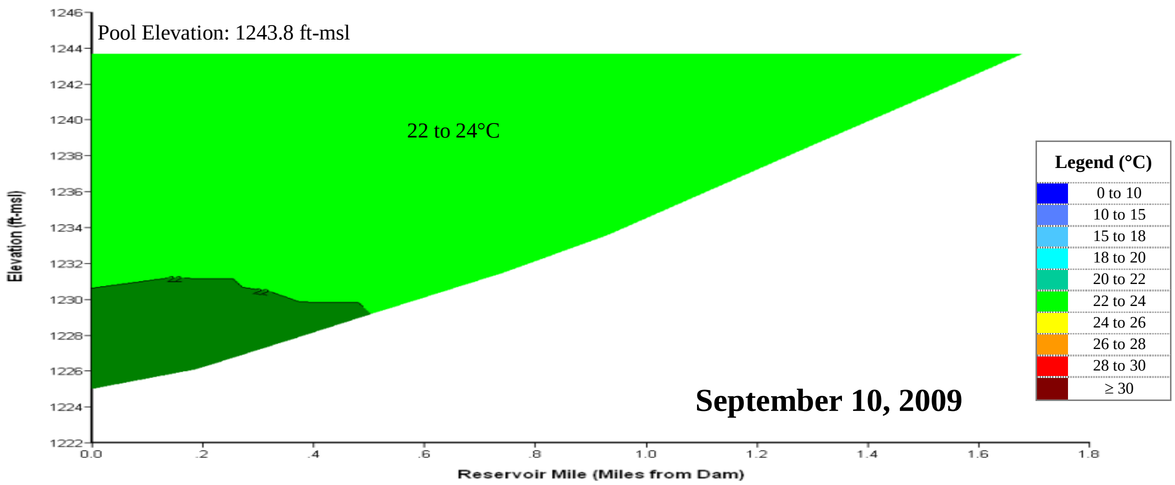


Plate 165. (Continued).

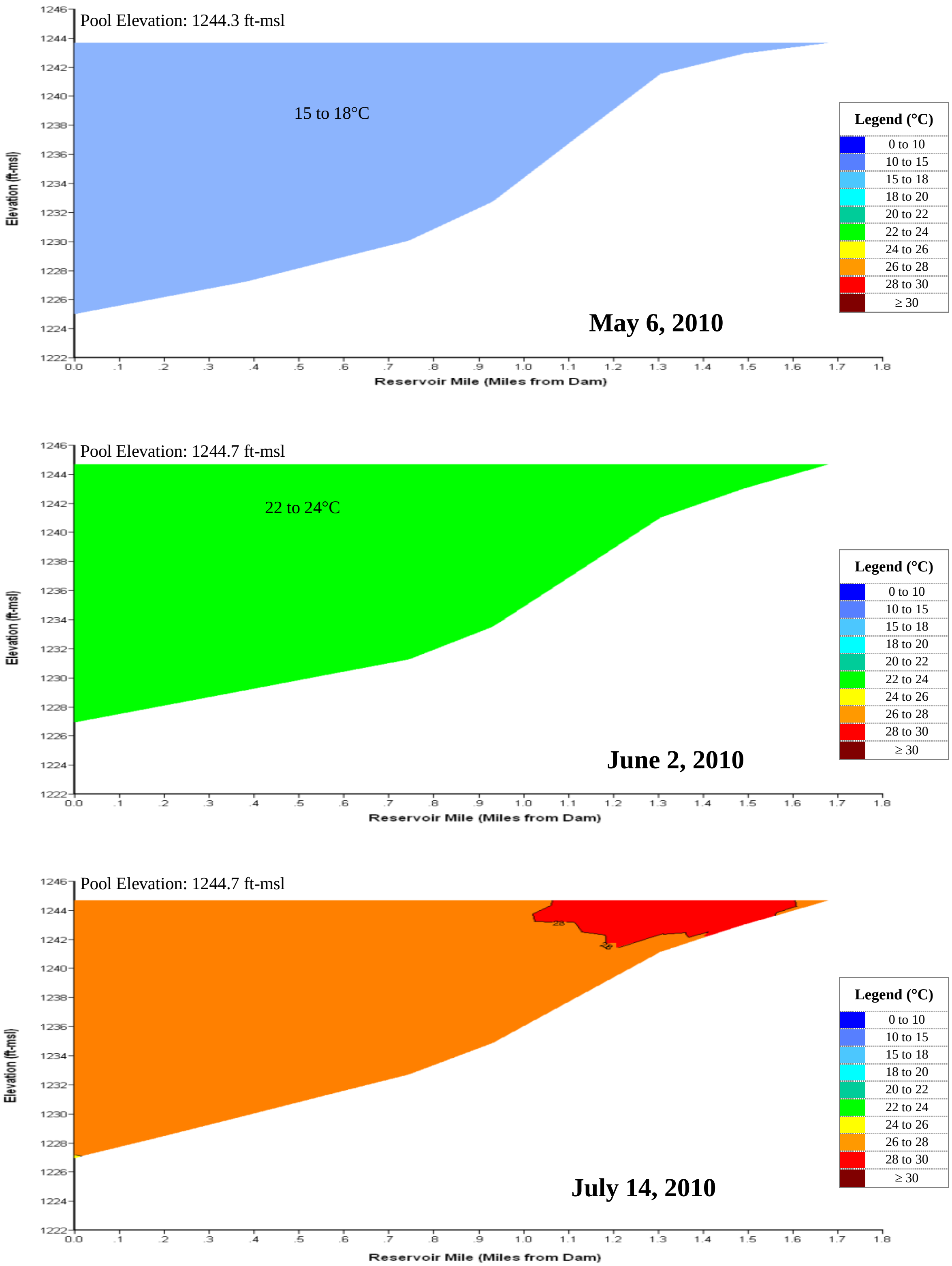
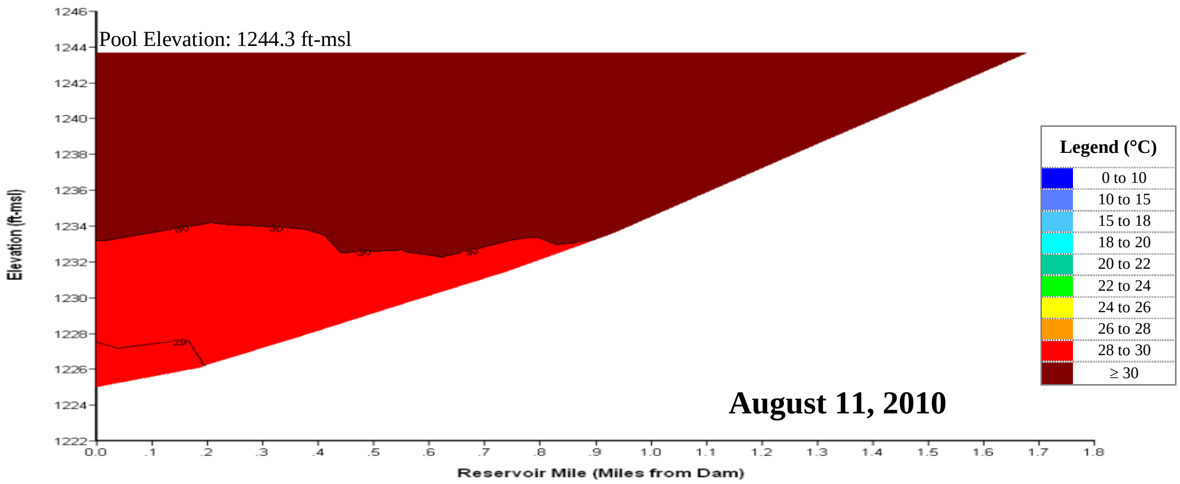


Plate 166. Longitudinal water temperature (°C) contour plots of Pawnee Reservoir based on depth-profile water temperatures measured at sites PAWLKND1, PAWLKML1, and PAWLKUP1 in 2010.



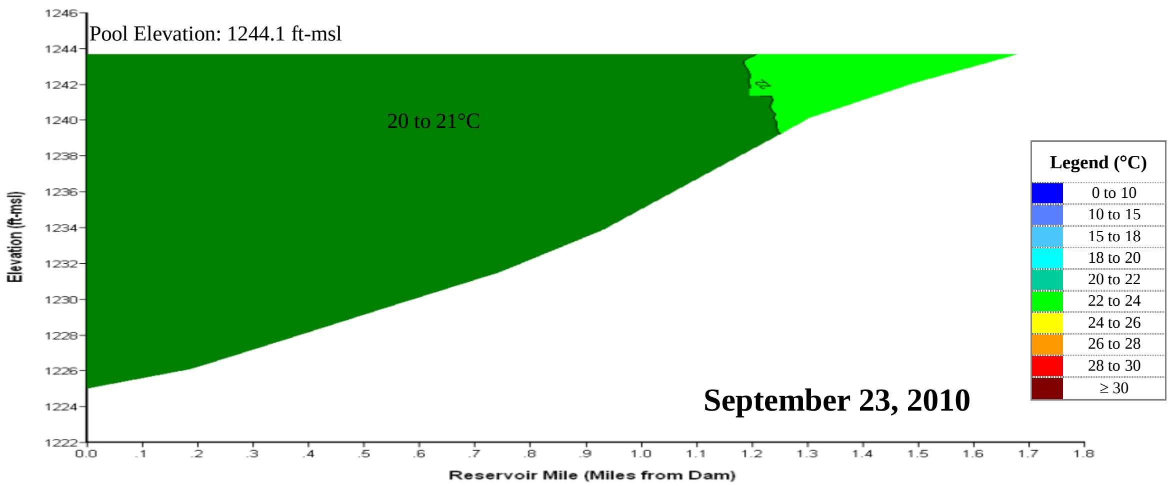


Plate 166. (Continued).

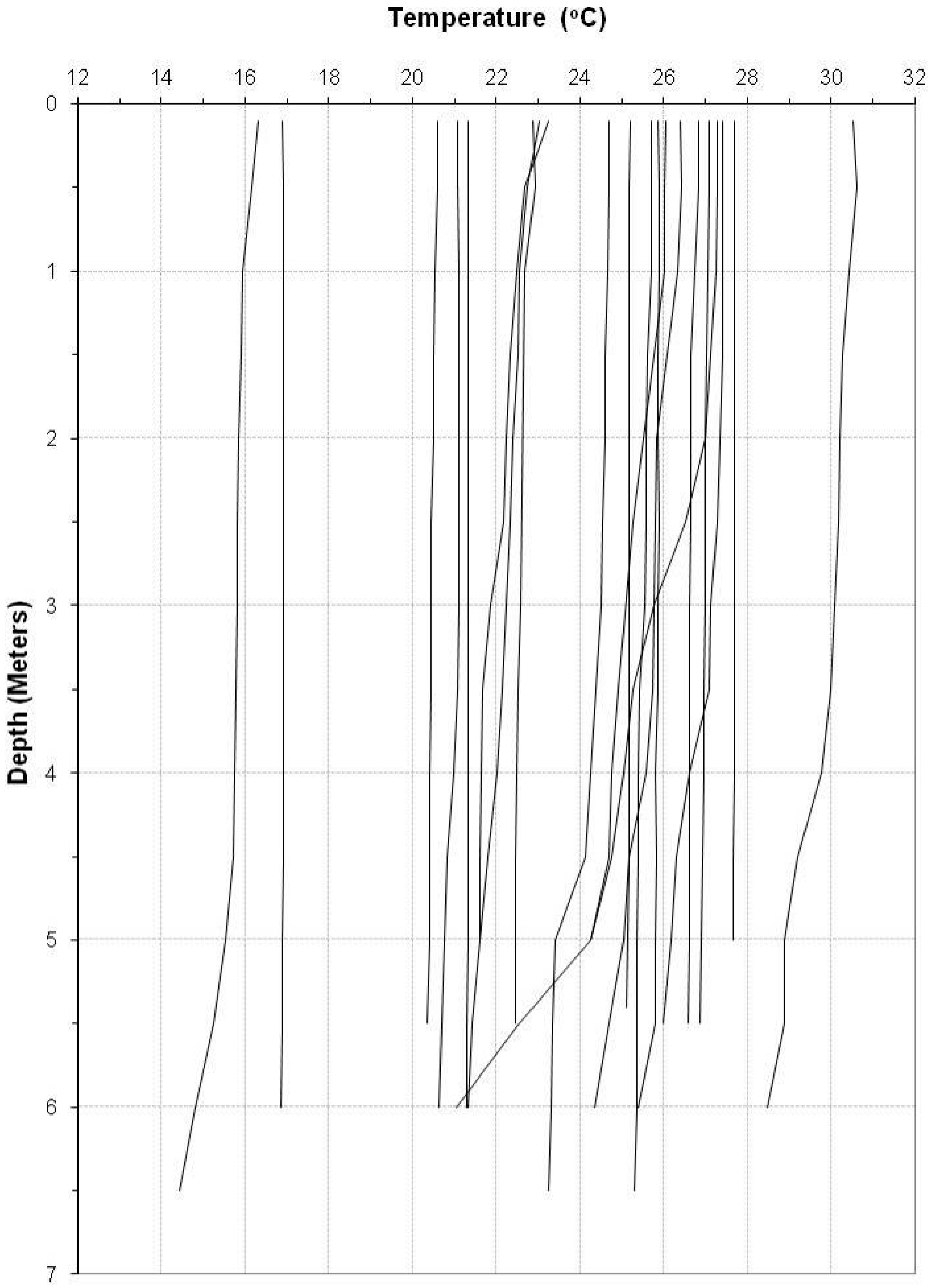


Plate 167. Temperature depth profiles for Pawnee Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., PAWLKND1) during the summer over the 5-year period of 2006 through 2010.

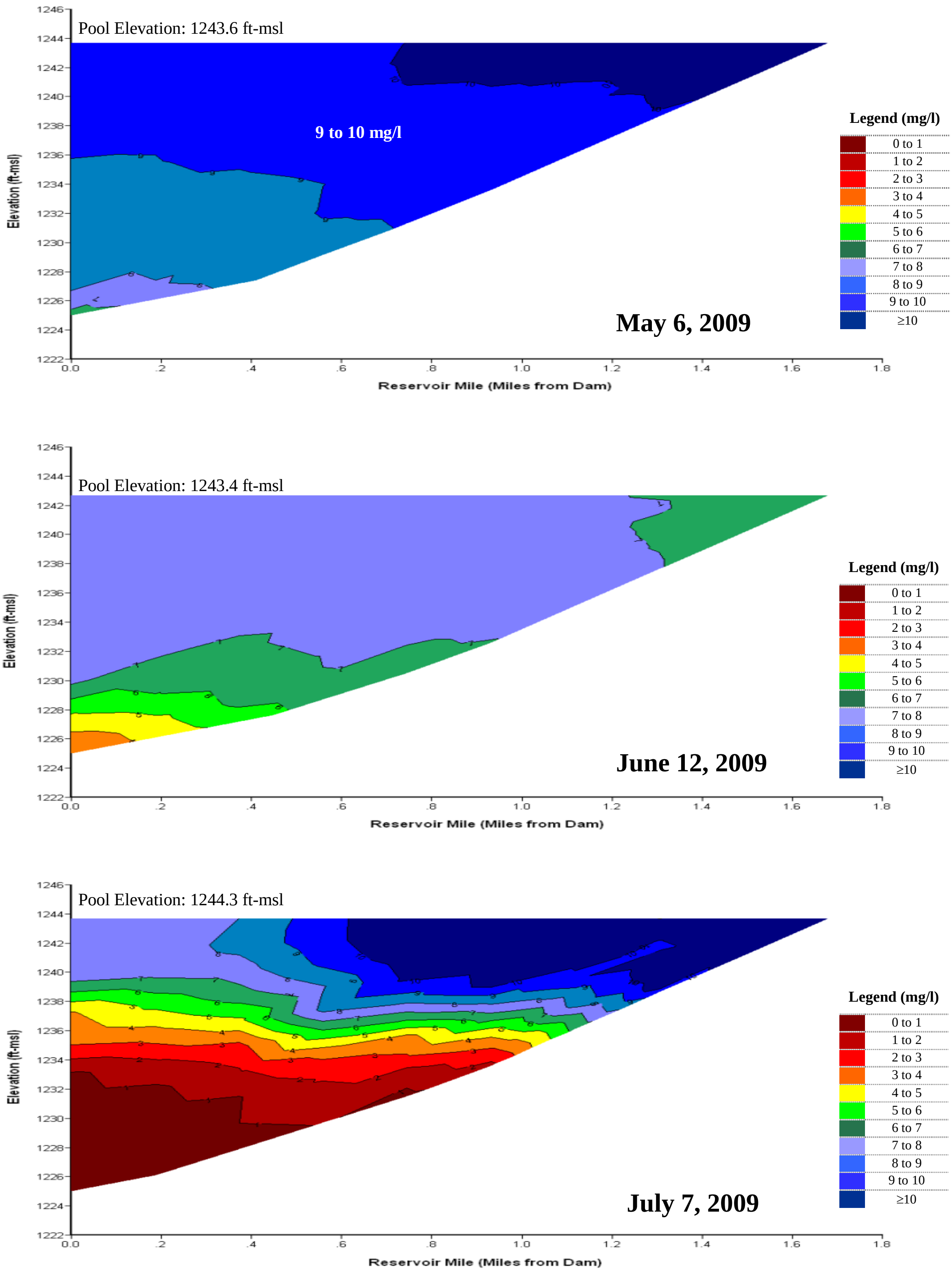
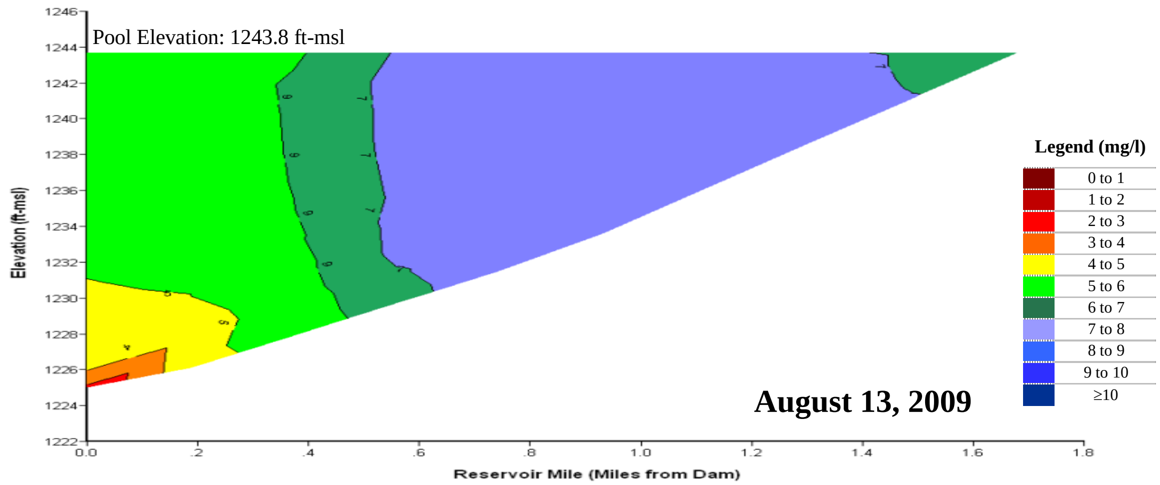


Plate 168. Longitudinal dissolved oxygen (mg/l) contour plots of Pawnee Reservoir based on depth-profile dissolved oxygen concentrations measured at sites PAWLKND1 and PAWLKML1 in 2009.



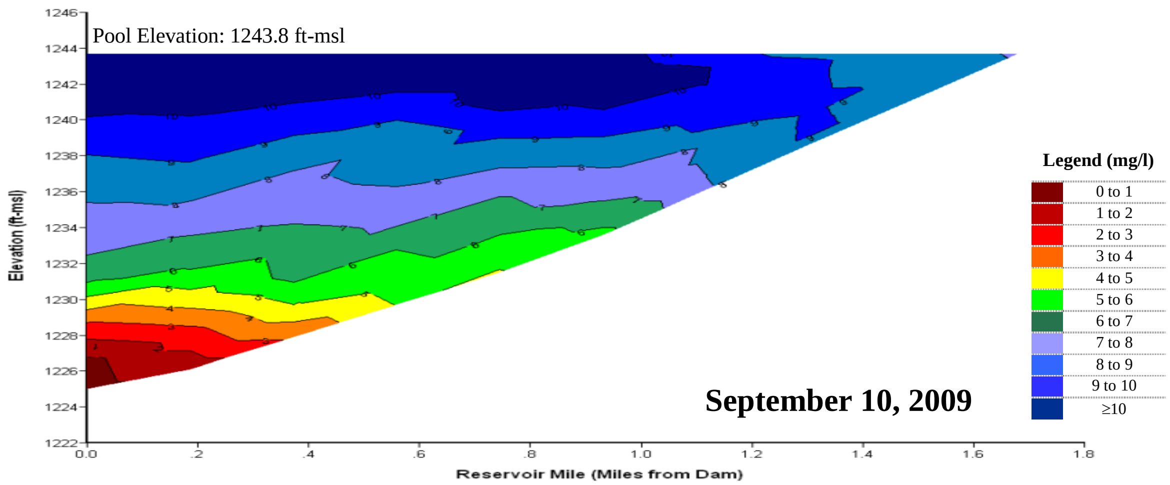


Plate 168. (Continued).

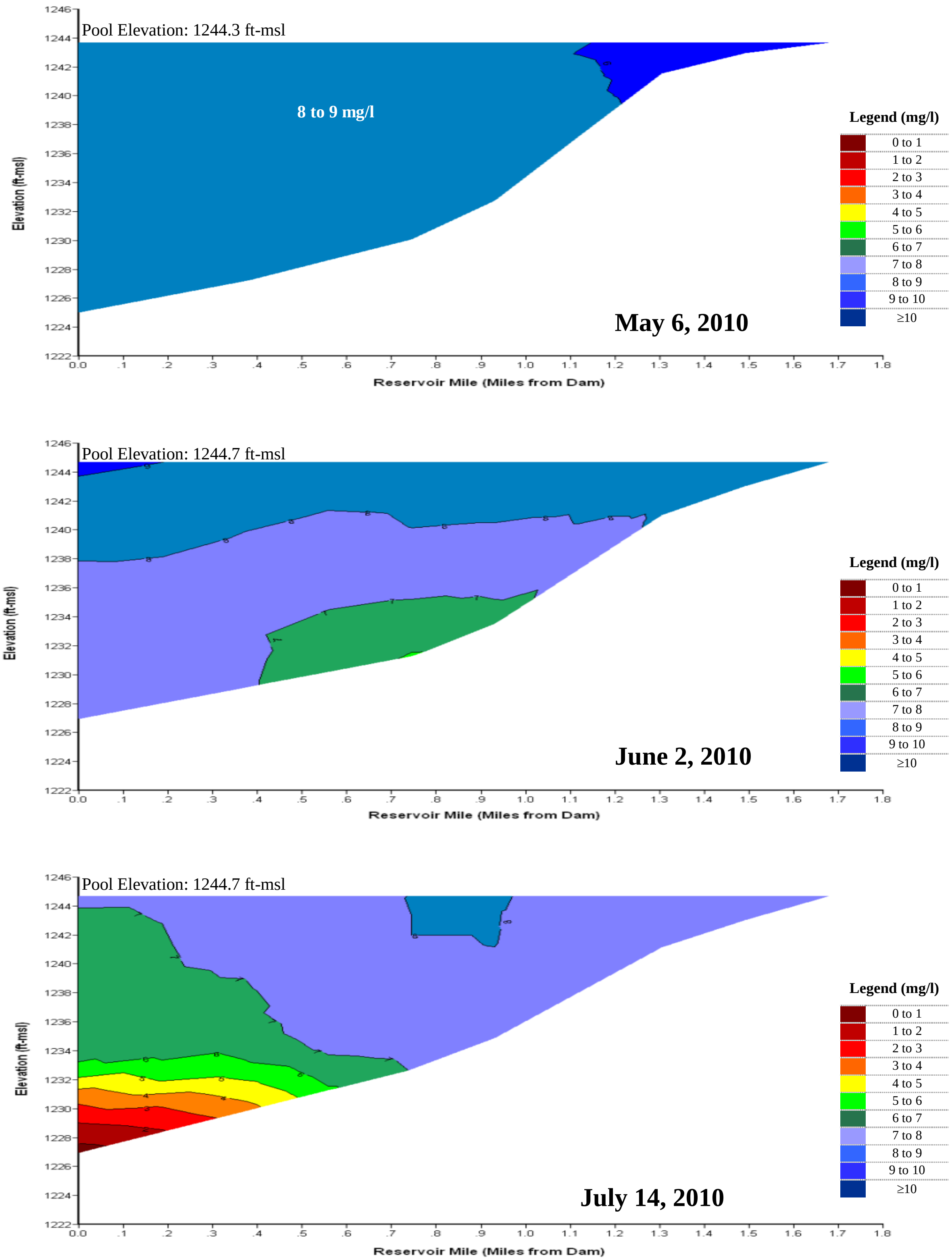
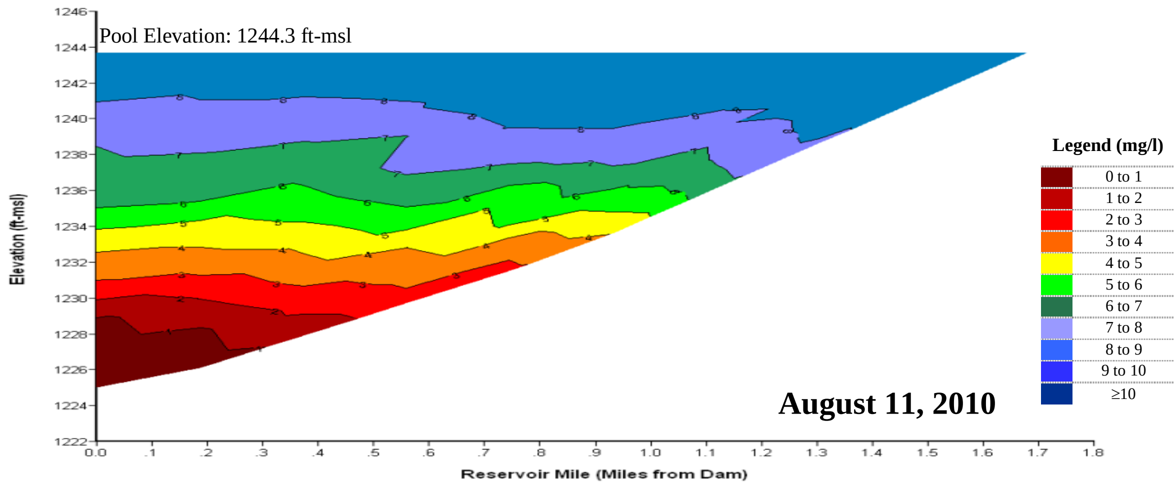


Plate 169. Longitudinal dissolved oxygen (mg/l) contour plots of Pawnee Reservoir based on depth-profile dissolved oxygen concentrations measured at sites PAWLKND1, PAWLKML1, and PAWLKUP1 in 2010.



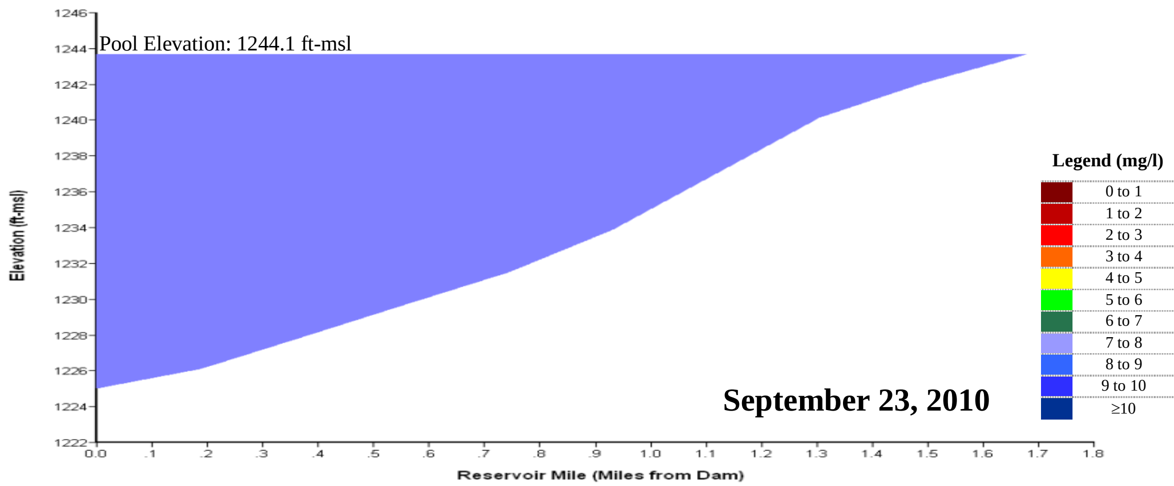


Plate 169. (Continued).

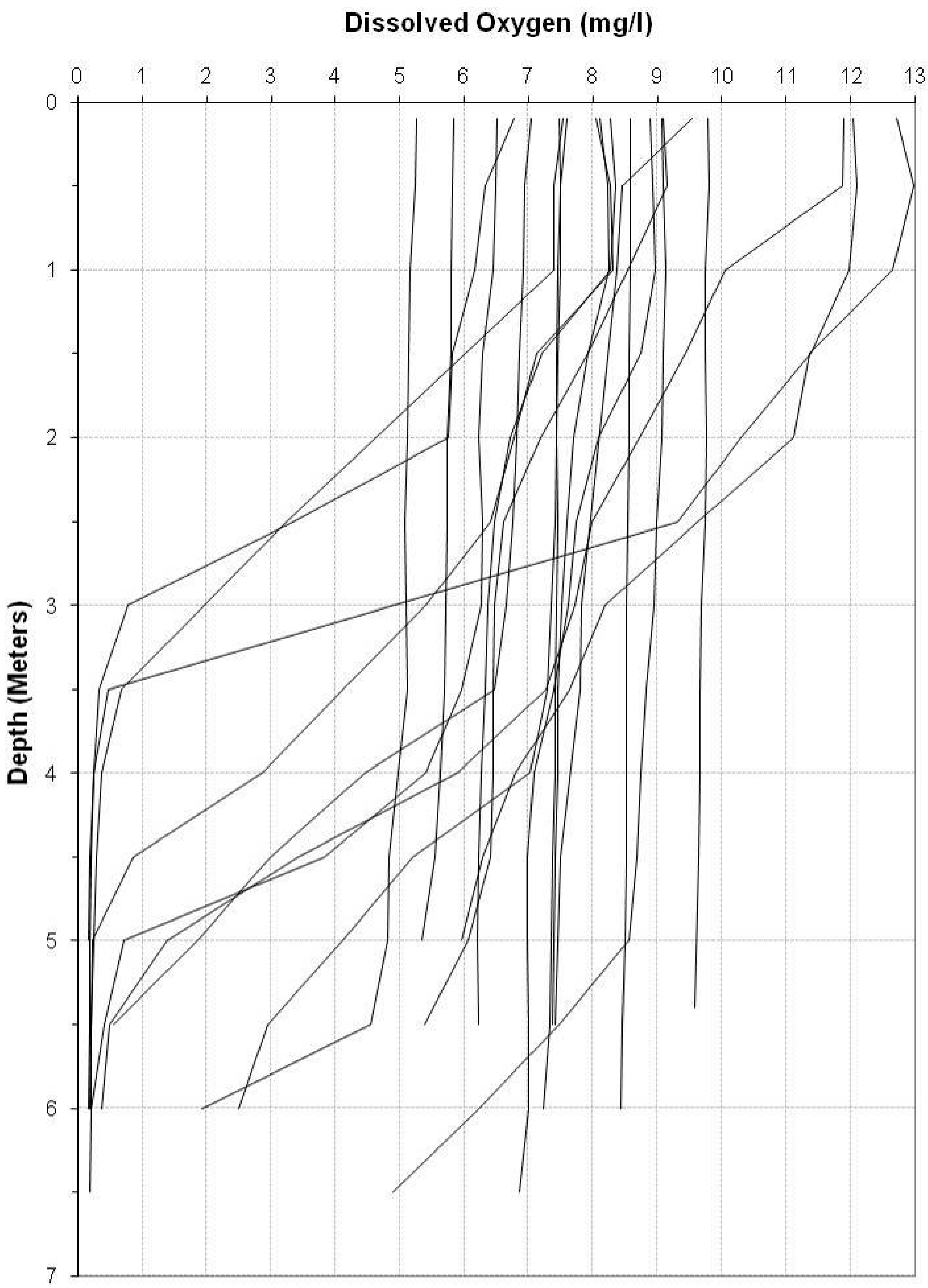


Plate 170. Dissolved oxygen depth profiles for Pawnee Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., PAWLKND1) during the summer of the 5-year period of 2006 through 2010.

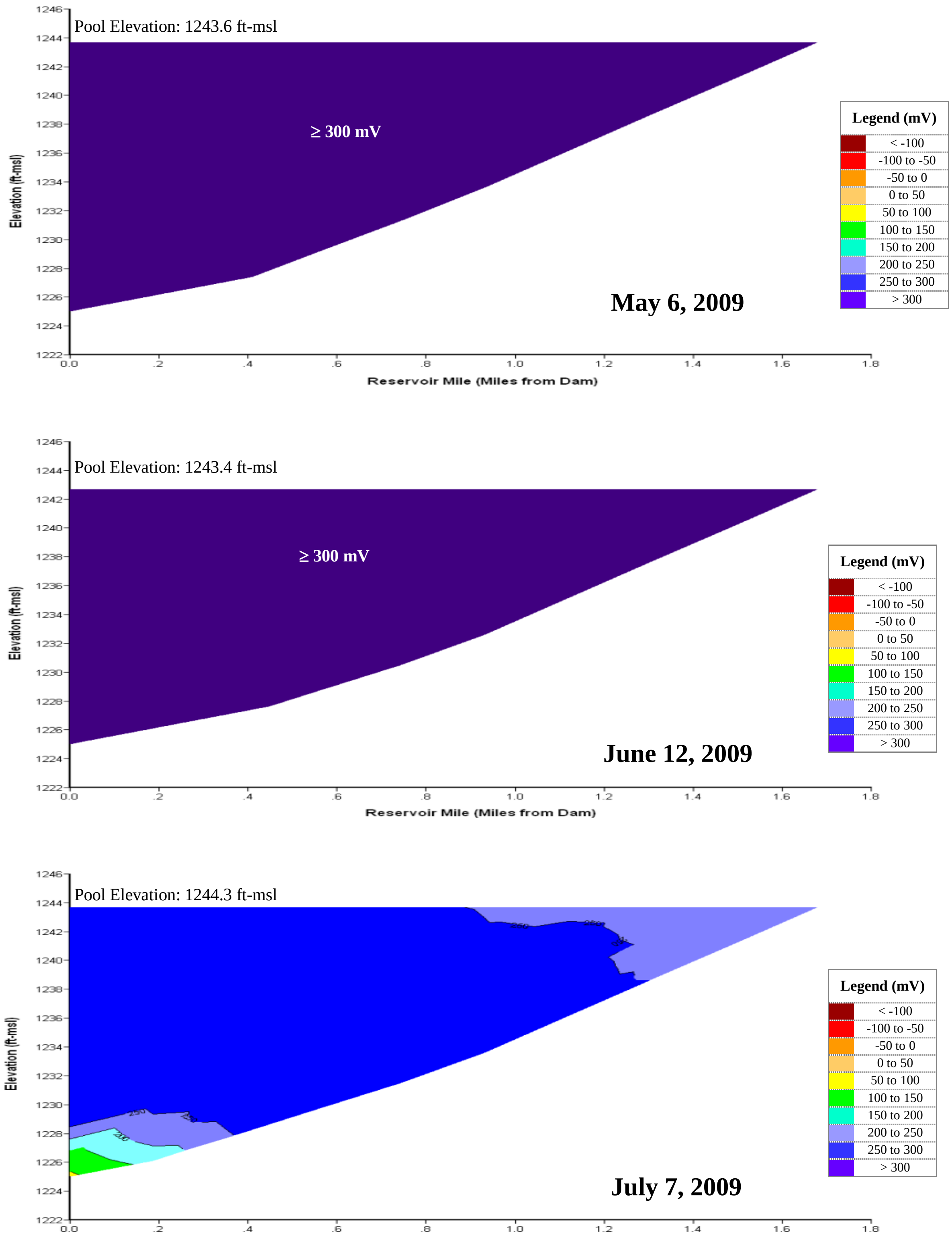
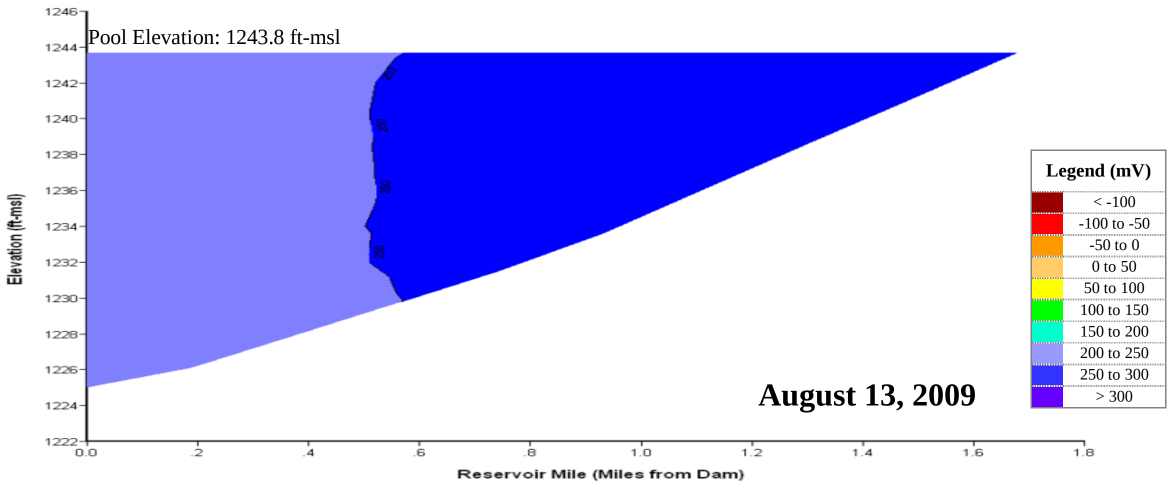


Plate 171. Longitudinal oxidation-reduction potential (mV) contour plots of Pawnee Reservoir based on depth-profile ORP levels measured at sites PAWLKND1 and PAWLKML1 in 2009.



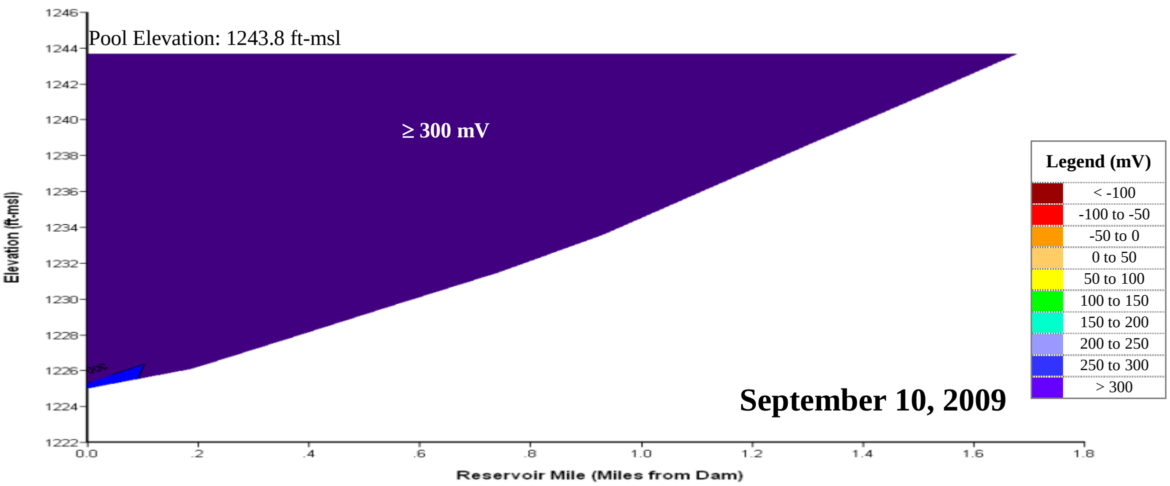
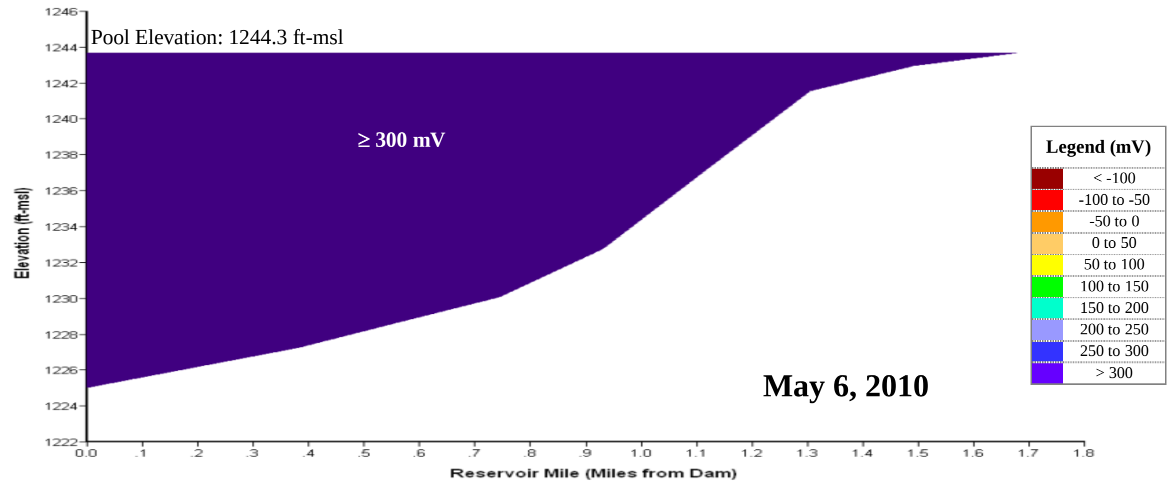
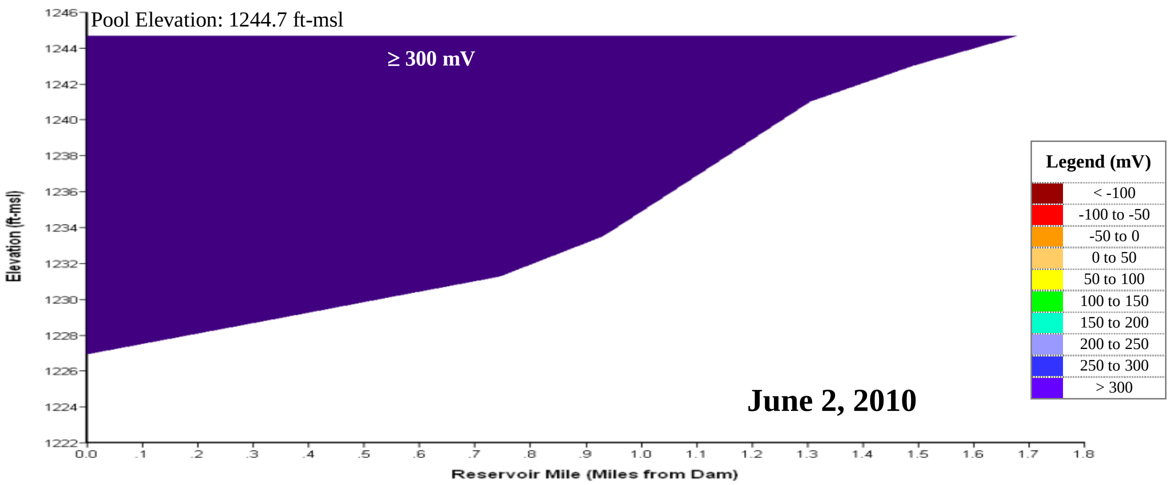


Plate 171. (Continued).





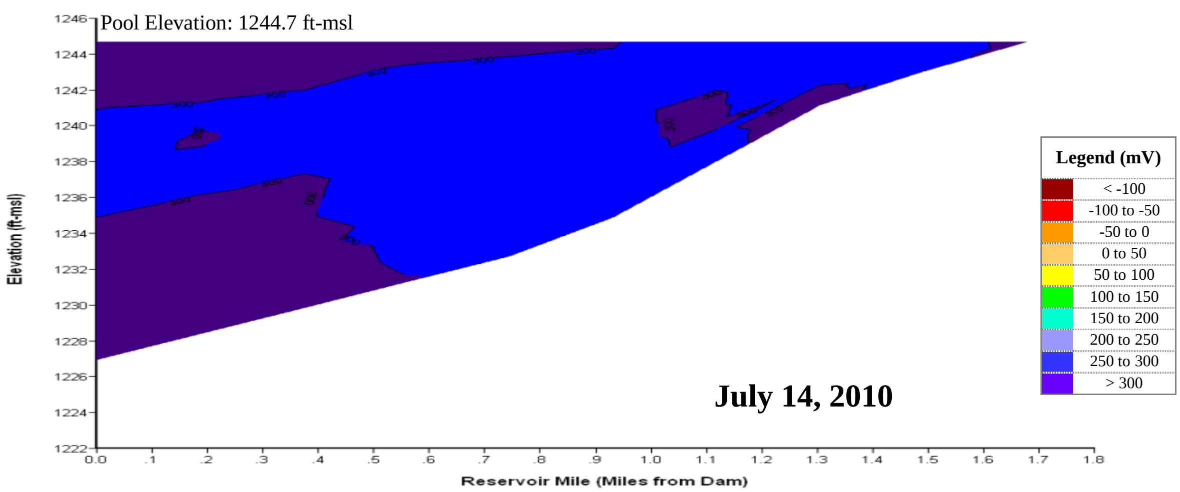
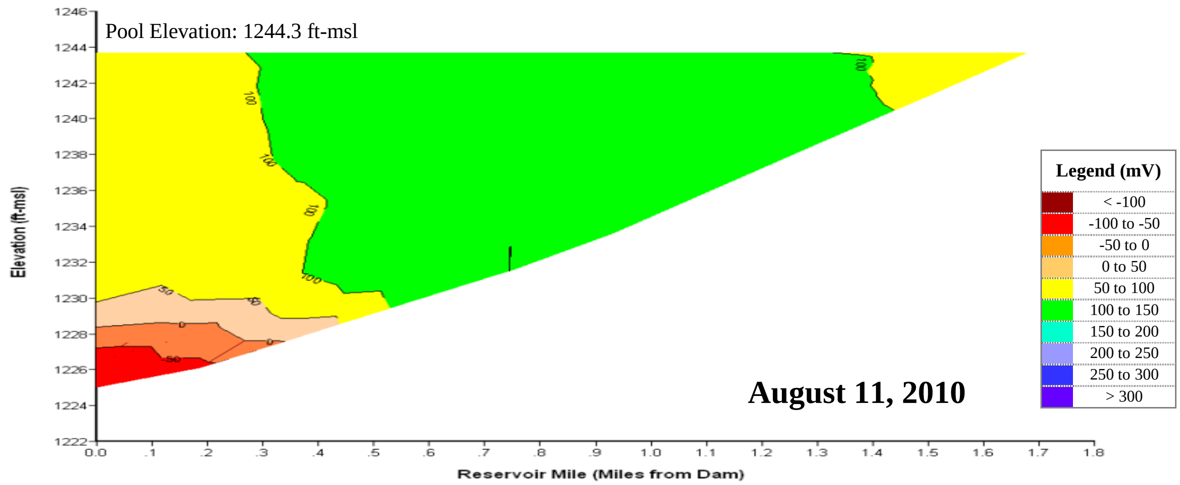


Plate 172. Longitudinal oxidation-reduction potential (mV) contour plots of Pawnee Reservoir based on depth-profile ORP levels measured at sites PAWLKND1, PAWLKML1, and PAWLKUP1 in 2010.



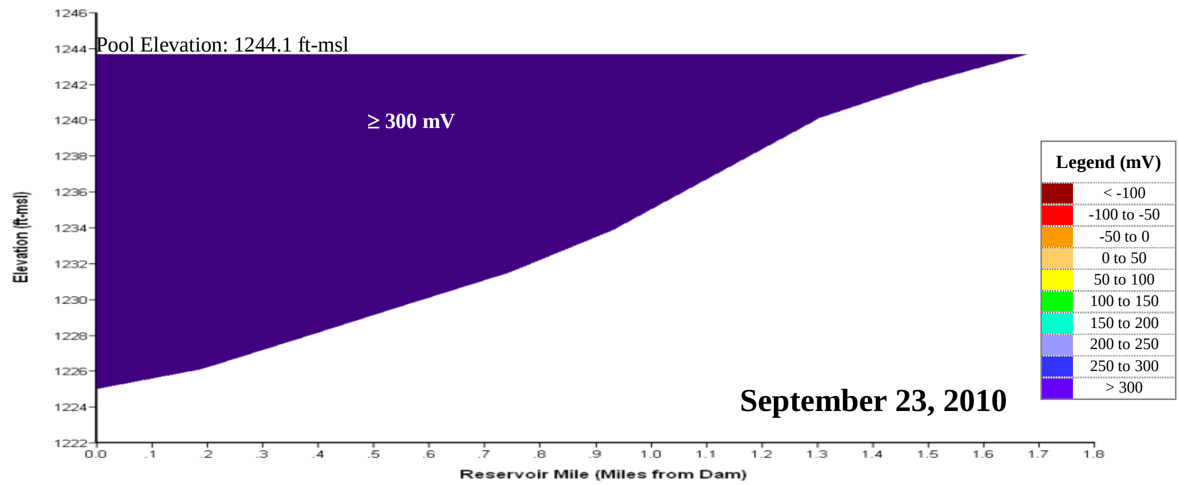


Plate 172. (Continued).

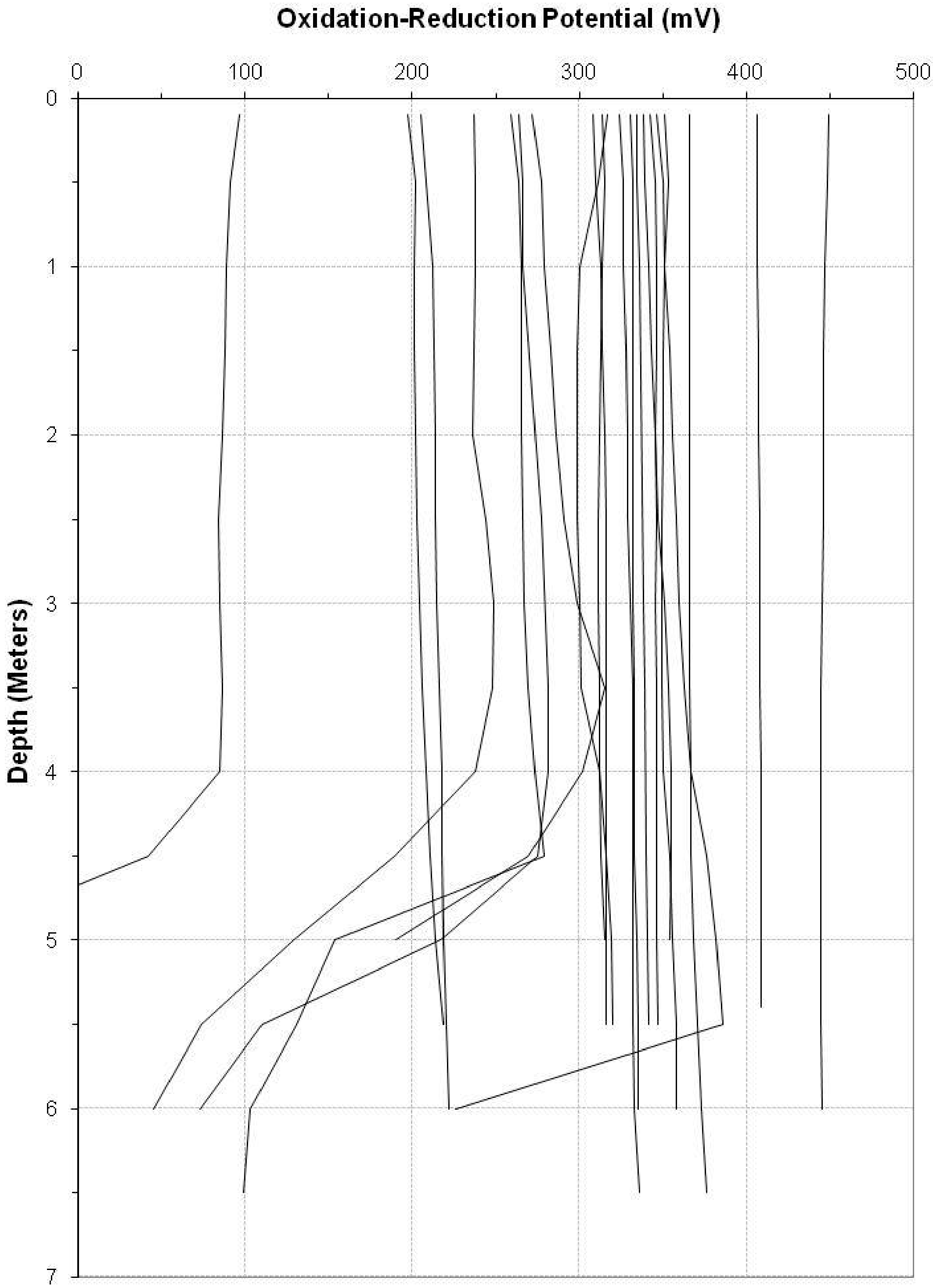
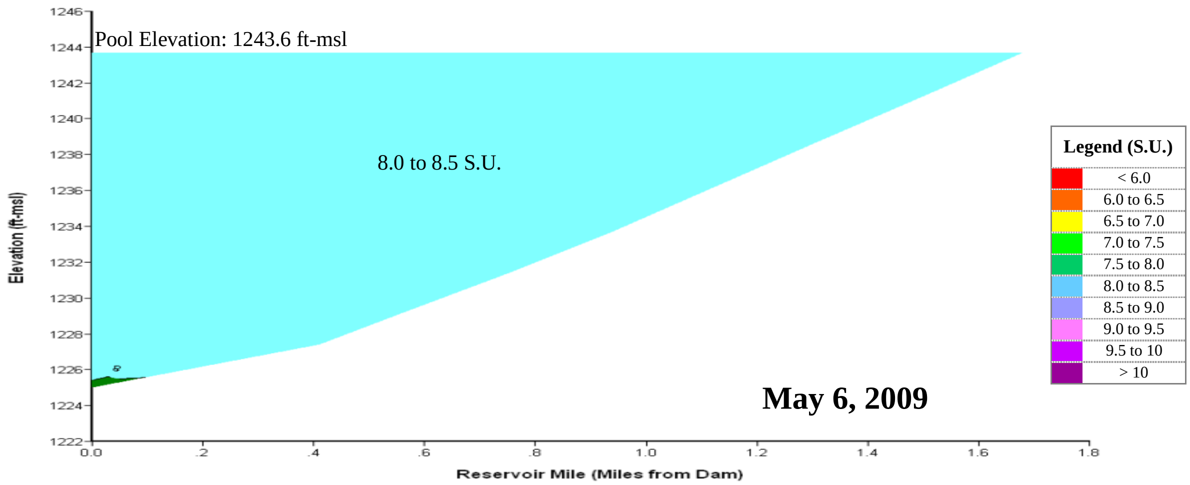
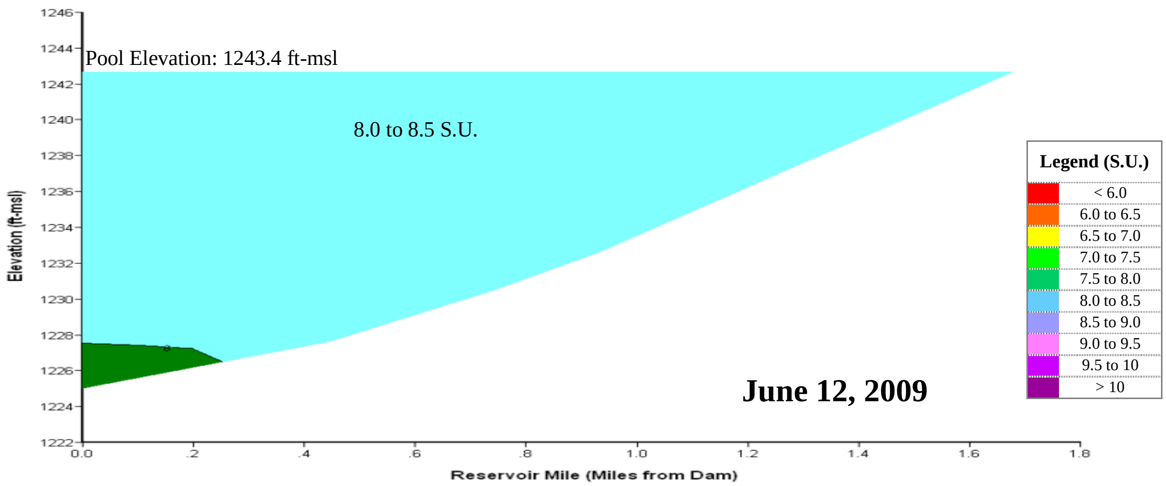


Plate 173. Oxidation-reduction potential depth profiles for Pawnee Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., PAWLKND1) during the summer of the 5-year period of 2006 through 2010.





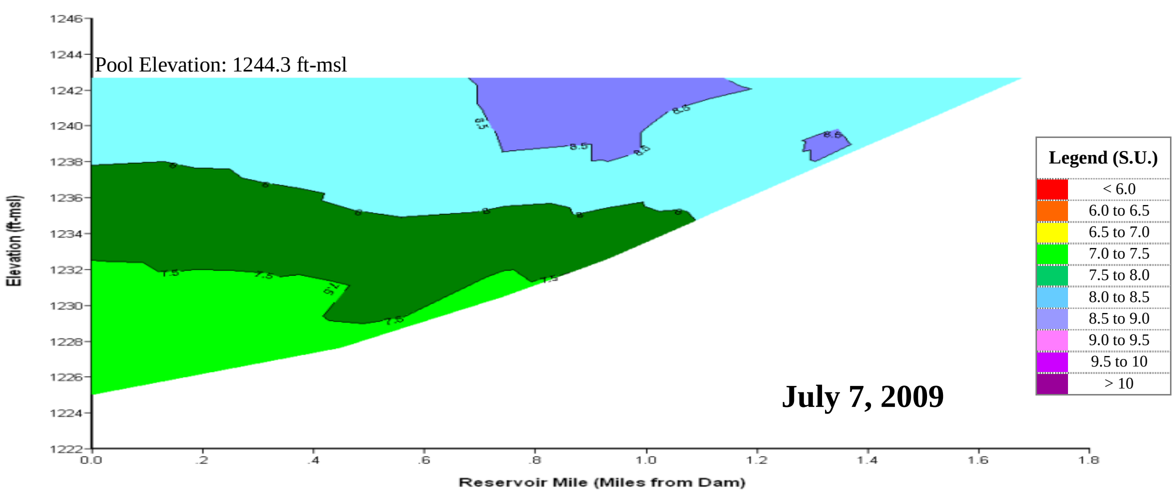
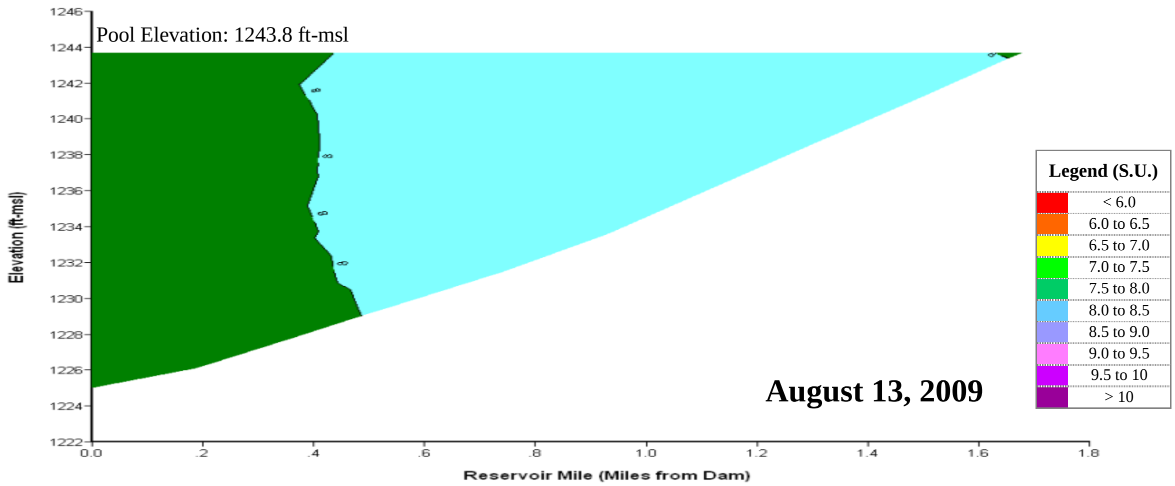


Plate 174. Longitudinal pH (S.U.) contour plots of Pawnee Reservoir based on depth-profile pH levels measured at sites PAWLKND1 and PAWLKML1 in 2009.



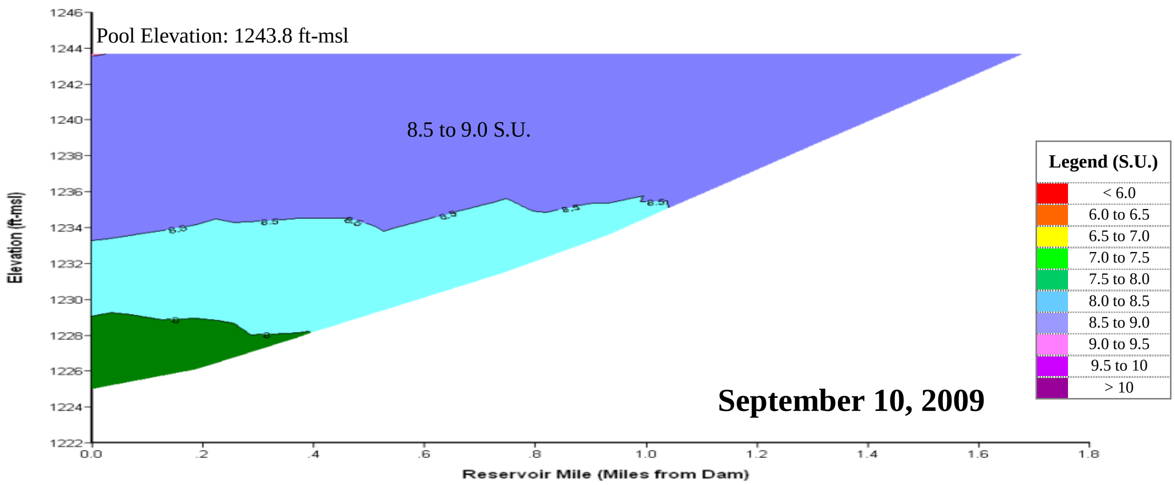
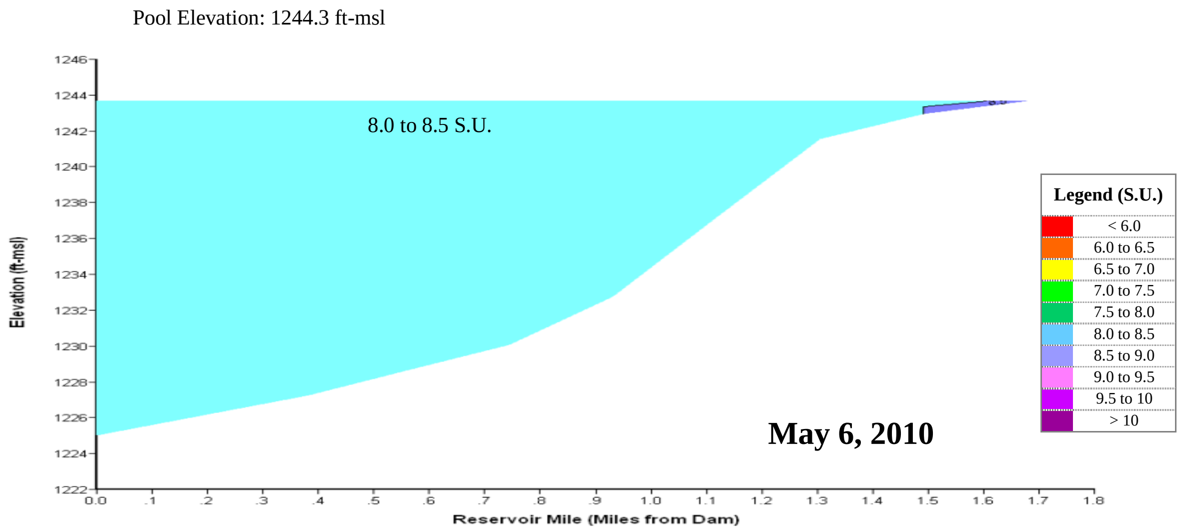
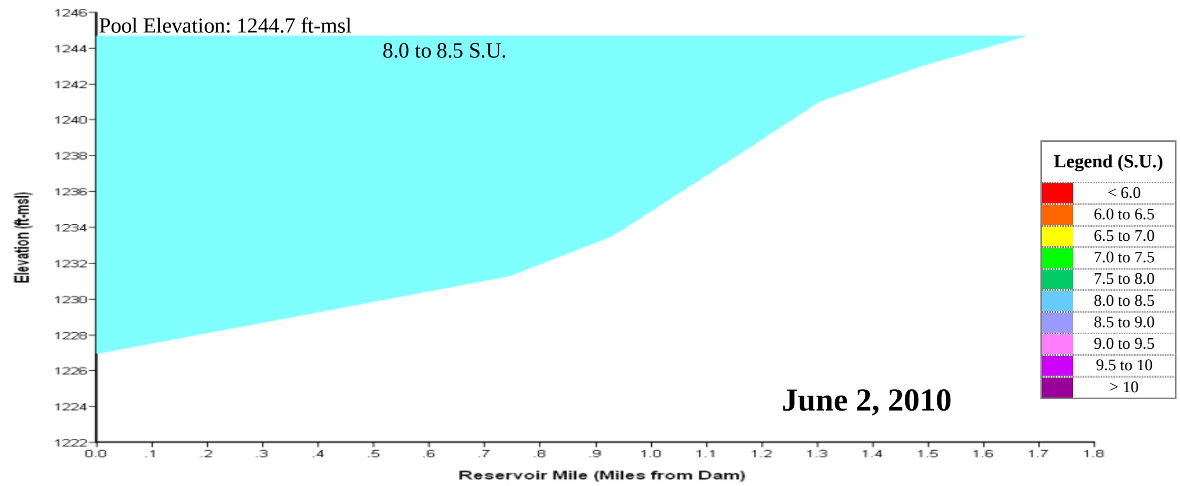


Plate 174. (Continued).





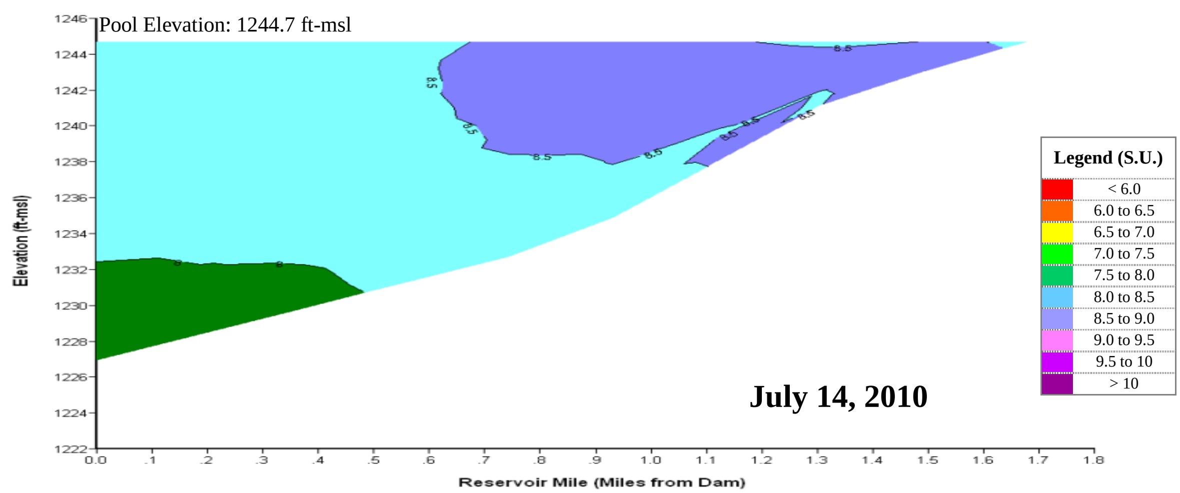
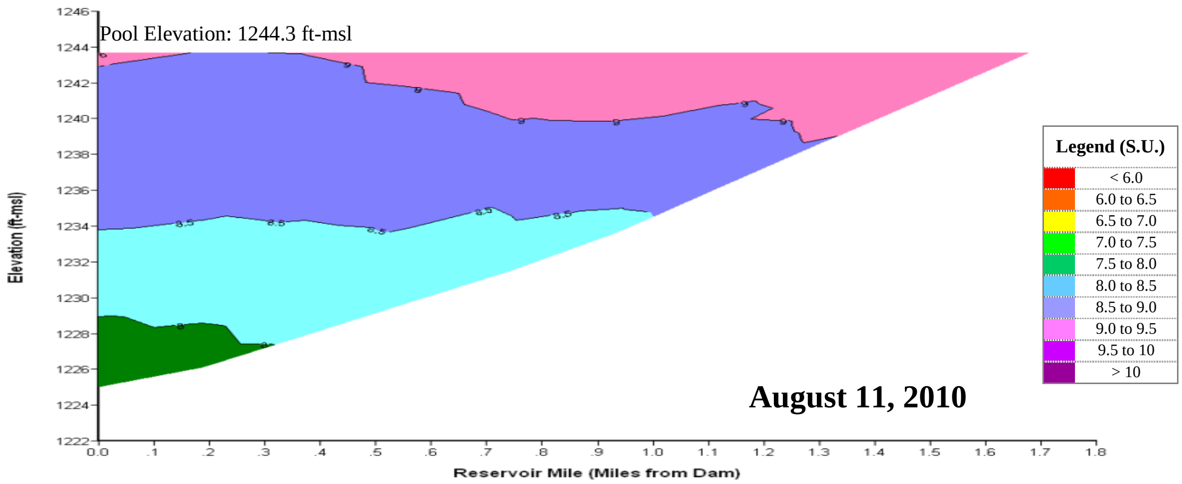


Plate 175. Longitudinal pH (S.U.) contour plots of Pawnee Reservoir based on depth-profile pH levels measured at sites PAWLKND1, PAWLKML1, and PAWLKUP1 in 2010.



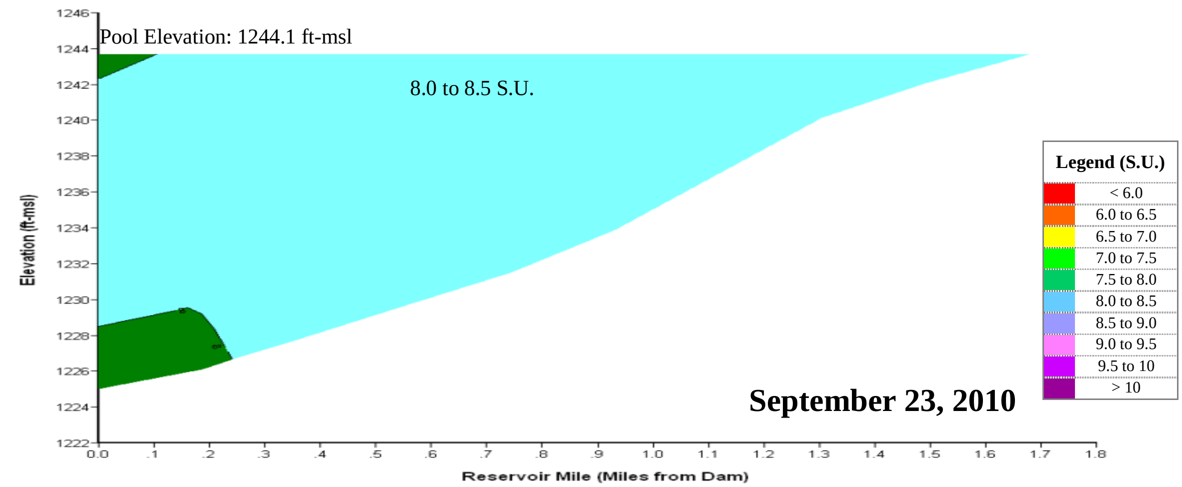


Plate 175. (Continued).

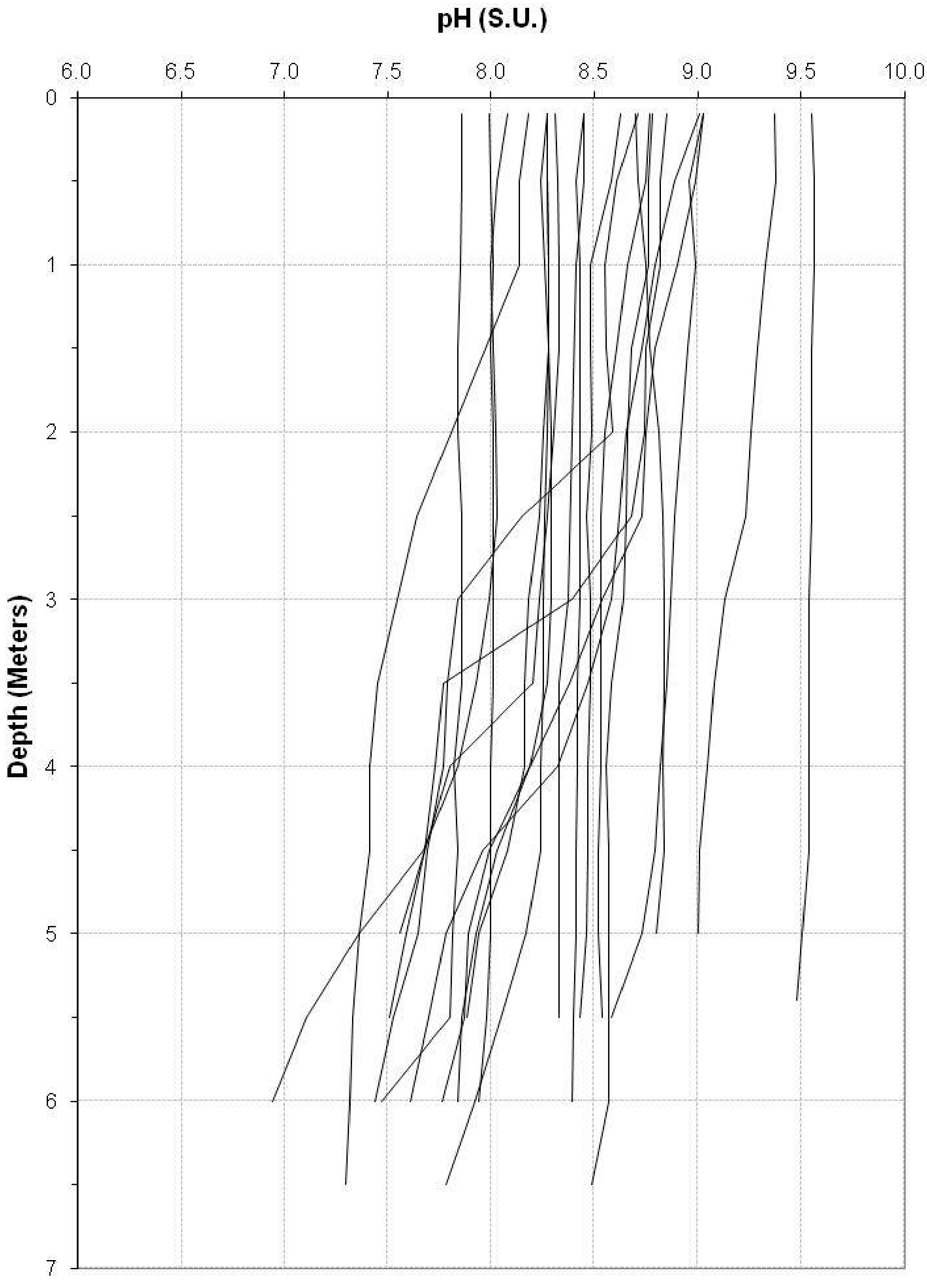


Plate 176. pH depth profiles for Pawnee Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., PAWLKND1) during the summer of the 5-year period of 2006 through 2010.

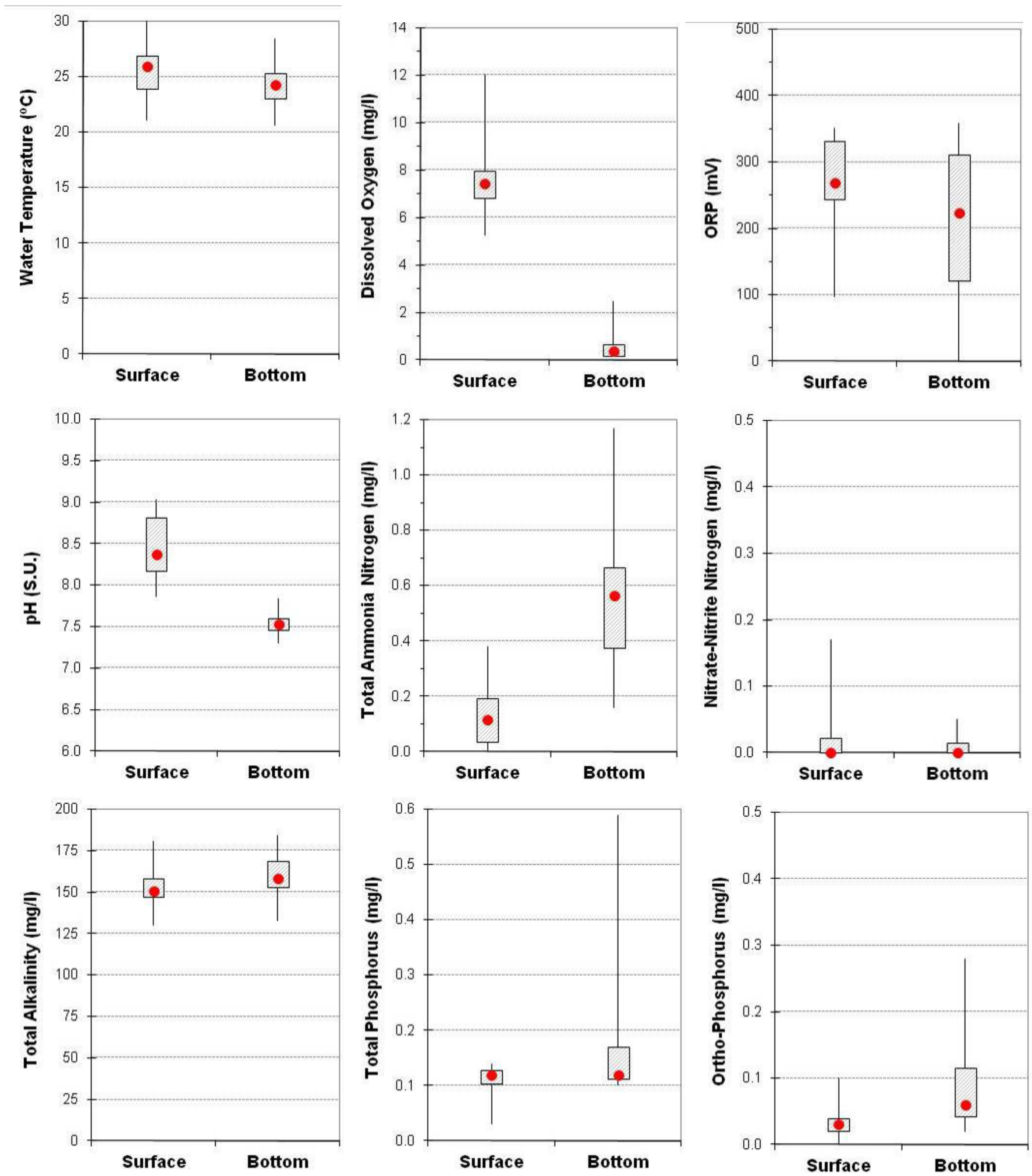


Plate 177. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, alkalinity, total ammonia nitrogen, nitrate-nitrite nitrogen, total phosphorus, and ortho-phosphorus measured in Pawnee Reservoir when summer hypoxic conditions were present during the 5-year period 2006 through 2010. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

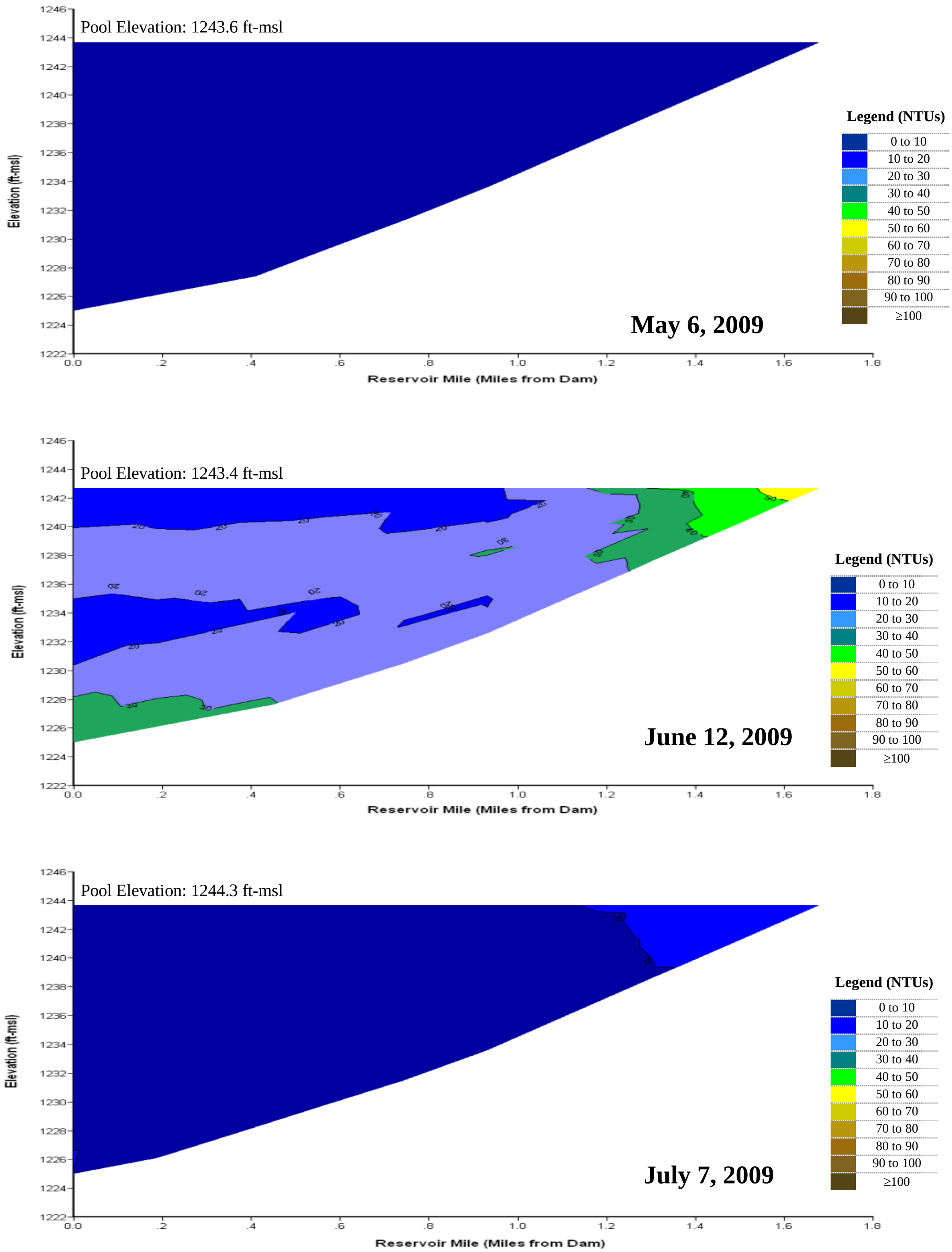
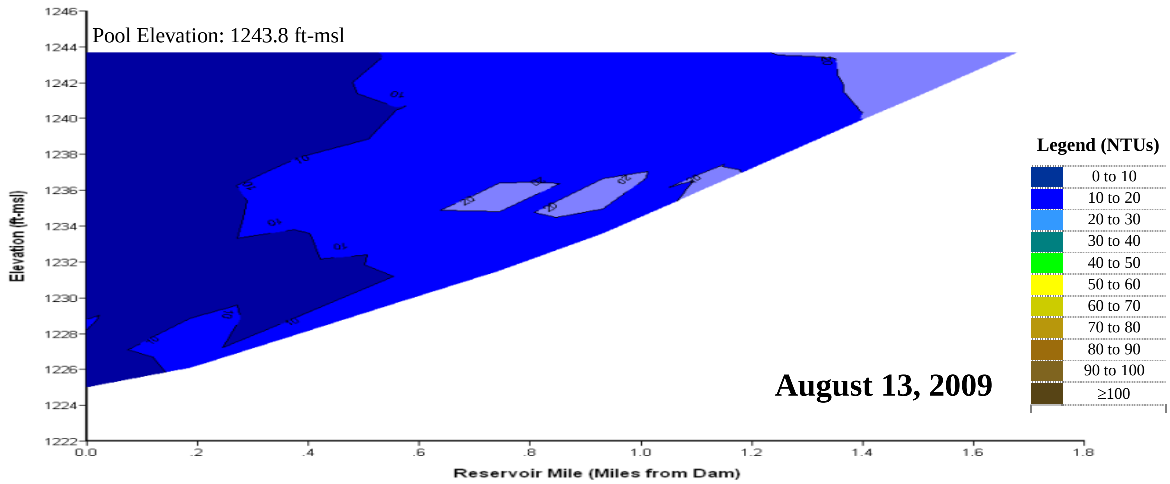


Plate 178. Longitudinal turbidity (NTU) contour plots of Pawnee Reservoir based on depth-profile turbidity levels measured at sites PAWLKND1 and PAWLKML1 in 2009.



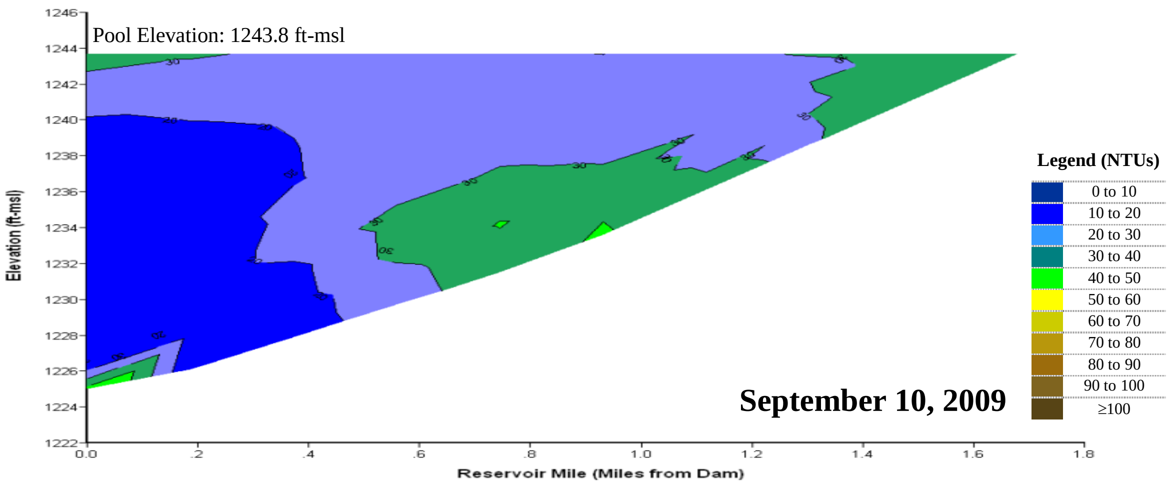


Plate 178. (Continued).

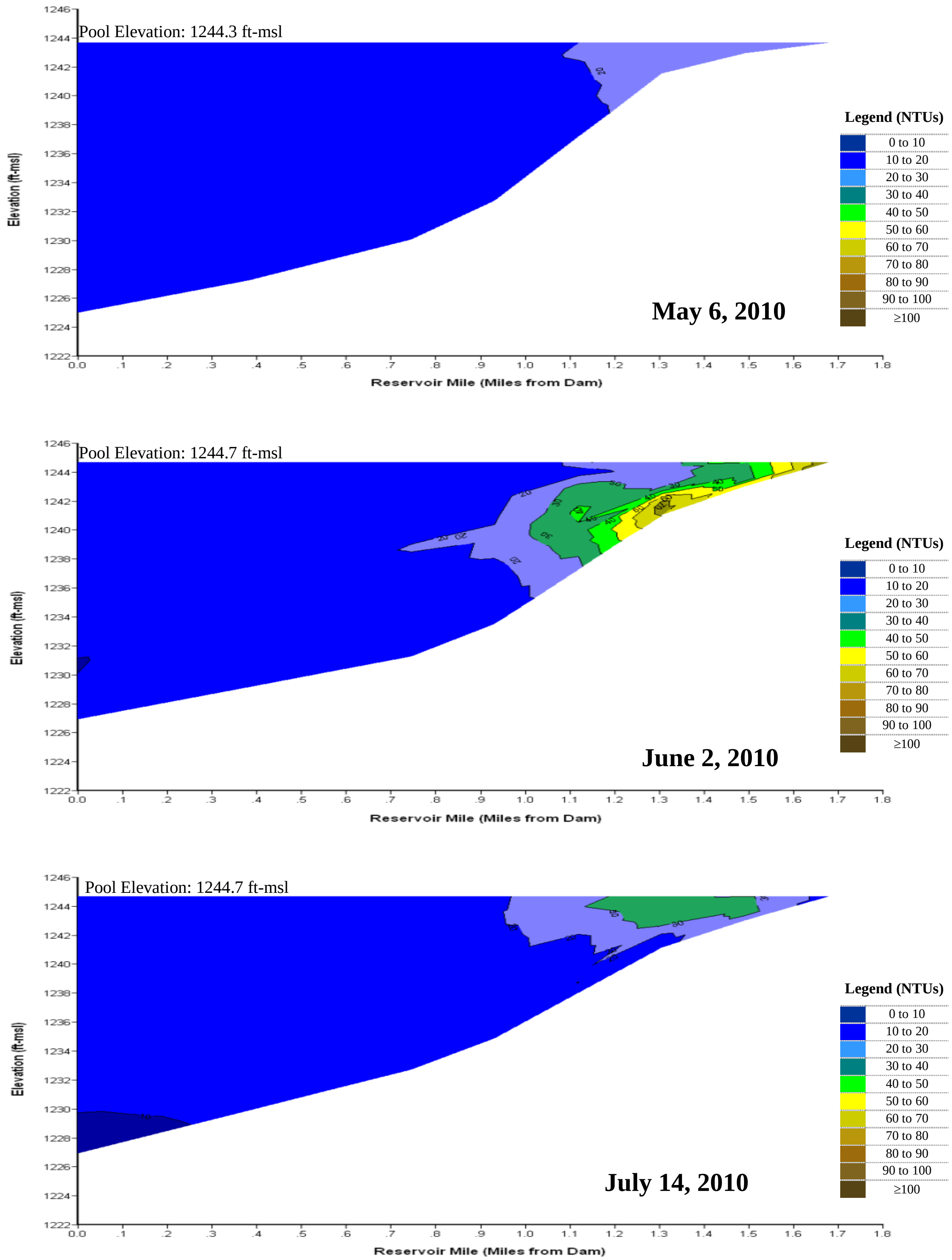
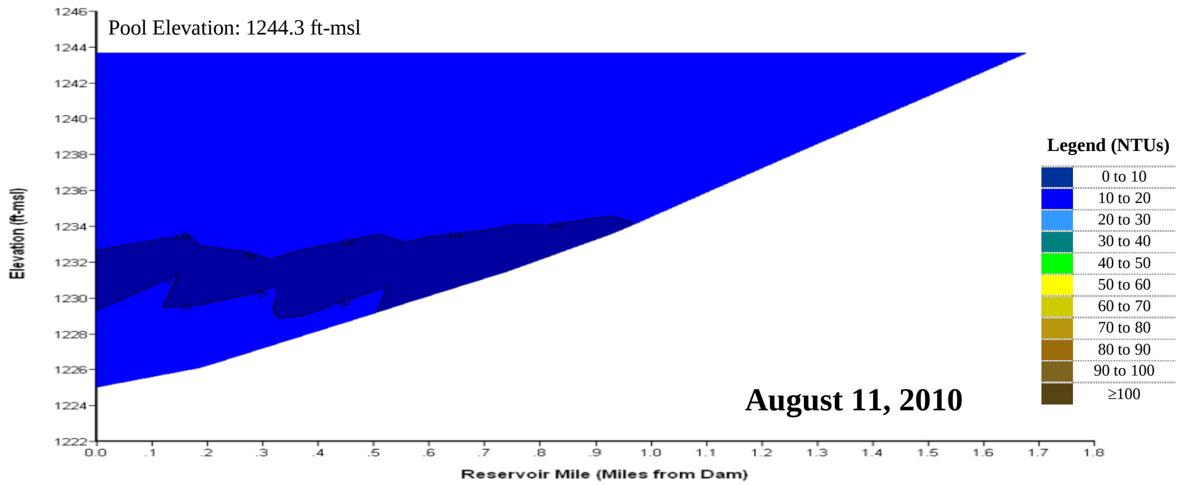


Plate 179. Longitudinal turbidity (NTU) contour plots of Pawnee Reservoir based on depth-profile turbidity levels measured at sites PAWLKND1, PAWLKML1, and PAWLKUP1 in 2010.



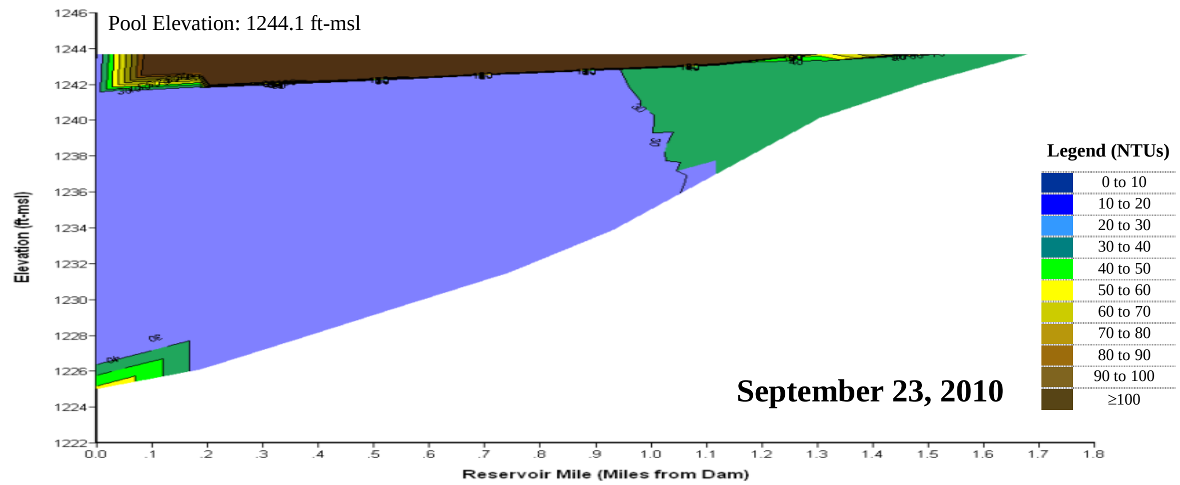


Plate 179. (Continued).

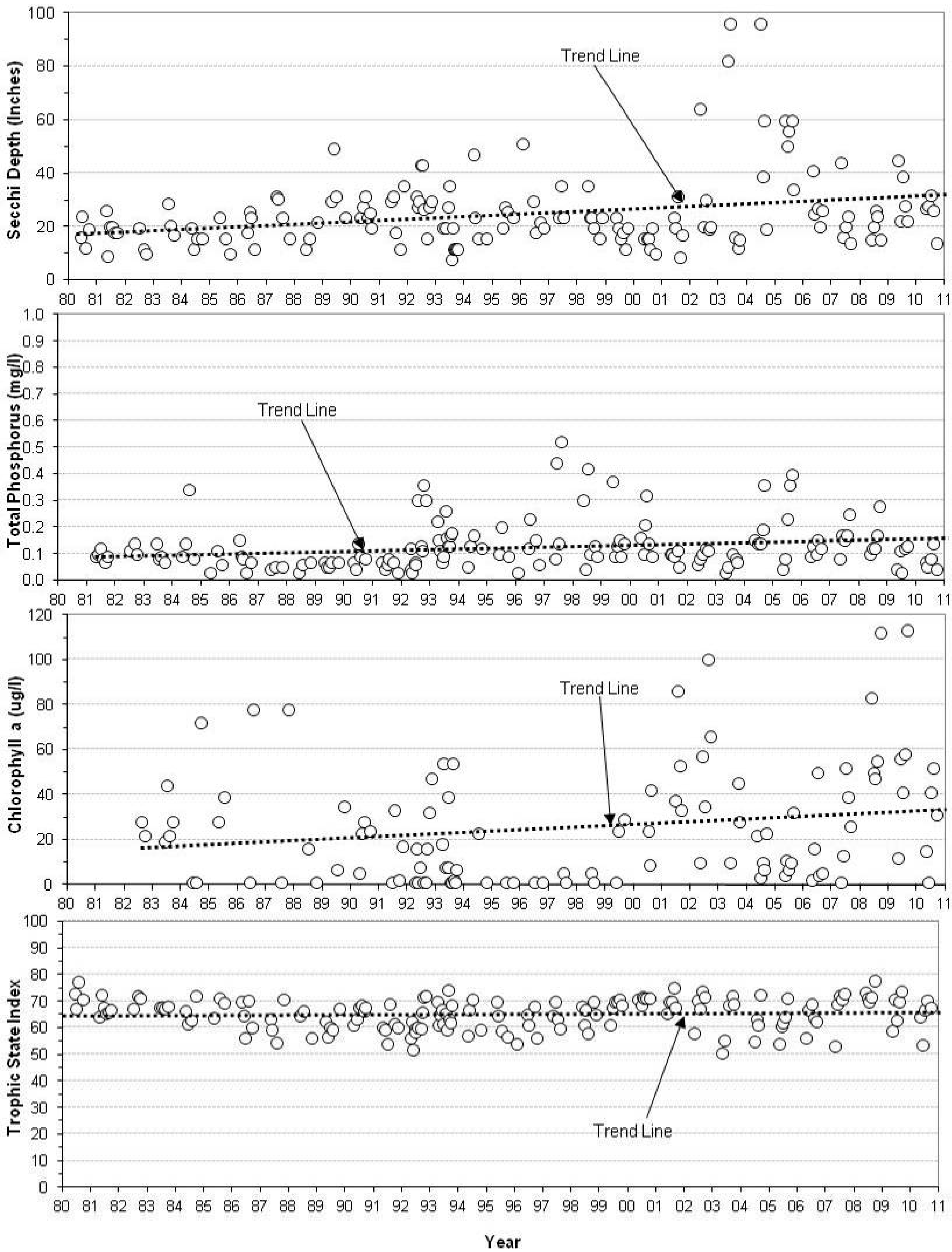


Plate 180. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Pawnee Reservoir at the near-dam, ambient site (i.e., site PAWLKND1) over the 31-year period of 1980 through 2010.

Plate 181. Summary of runoff water quality conditions monitored in the main tributary inflow to Pawnee Reservoir at monitoring site PAWNF1 during the 5-year period 2004 through 2008**.** Runoff conditions have not been monitored since 2008.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Kjeldahl N, Total (mg/l)	0.1	5	3.3	2.4	1.9	7.1	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	5	0.91	0.73	n.d.	2.17	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	5	1.06	0.76	0.57	2.30	-----	-----	-----
Suspended Solids, Total (mg/l)	4	5	549	392	48	1,700	-----	-----	-----
Acetochlor, Total (ug/l)[C]	0.05	3	7.26	1.46	0.82	19.50	-----	-----	-----
Alachlor, Total (ug/l)[C]	0.05	2	0.54	0.54	0.17	0.90	760[1], 76[2]	0	0%
Atrazine, Total (ug/l)[C]	0.05	5	3.92	1.27	0.53	15.10	330[1], 12[2]	0, 1	0%, 20%
Metolachlor, Total (ug/l)[C]	0.05	5	1.18	1.09	0.09	3.11	390[1], 100[2]	0	0%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Acute criterion for aquatic life.
(2) Chronic criterion for aquatic life.
(C) Immunoassay analysis.

Plate 182. Summary of water quality conditions monitored in Stagecoach Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site STGLKND1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	25	1271.2	1271.0	1270.4	1274.1	-----	-----	-----
Water Temperature (°C)	0.1	199	23.4	24.9	15.3	28.6	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	199	6.5	6.8	0.6	10.1	≥ 5[2]	45	23%*
Dissolved Oxygen (% Sat.)	0.1	192	78.8	80.0	7.4	128.5	-----	-----	-----
Specific Conductance (umho/cm)	1	199	387	402	159	485	2,000[3]	0	0%
pH (S.U.)	0.1	199	8.1	8.0	7.1	8.7	≥6.5 & ≤9.0[1]	0	0%
Turbidity (NTUs)	1	199	72	33	4	1239	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	199	343	349	229	496	-----	-----	-----
Secchi Depth (in.)	1	24	18	15	5	51	-----	-----	-----
Alkalinity, Total (mg/l)	7	50	135	131	67	200	20[1]	0	0%
Ammonia, Total (mg/l)	0.02	50	-----	0.12	n.d.	0.67	8.40 [4,5], 1.35 [4,6]	0	0%
Chlorophyll *a* (ug/l) – Field Probe	1	150	20	9	1	92	10[7]	72	48%
Chlorophyll *a* (ug/l) – Lab Determined	1	24	19	10	n.d.	87	10[7]	11	46%
Hardness, Total (mg/l)	0.4	5	135.2	129.0	114.0	162.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.10	50	1.4	1.2	0.8	7.5	-----	-----	-----
Nitrogen, Total (mg/)	0.10	50	1.8	1.4	0.8	7.6	1 [7]	30	100%
Nitrate-Nitrite N, Total (mg/l)	0.02	50	-----	0.05	n.d.	2.20	100[3]	0	0%
Phosphorus, Total (mg/l)	0.10	50	0.2	0.1	n.d.	0.6	0.05[7]	49	98%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	-----	0.03	n.d.	0.16	-----	-----	-----
Suspended Solids, Total (mg/l)	4	50	28	19	n.d.	277	-----	-----	-----
Aluminum, Dissolved (ug/l)	25	5	-----	n.d.	n.d.	n.d.	750[5], 87[6]	0	0%
Antimony, Dissolved (ug/l)	6	5	-----	1	n.d.	1	88[5], 30[6]	0	0%
Arsenic, Dissolved (ug/l)		5	-----	2	n.d.	4	340[5], 16.7[8]	0	0%
Beryllium, Dissolved (ug/l)	3	5	-----	n.d.	n.d.	n.d.	130[5], 5.3[6]	0	0%
Cadmium, Dissolved (ug/l)	0.5	3	-----	n.d.	n.d.	n.d.	7.6[5], 0.3[6]	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	729[5], 95[6]	0	0%
Copper, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	17[5], 11[6]	0	0%
Lead, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	85[5], 3.3[6]	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4[5]	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77[6]	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	581[5], 65[6]	0	0%
Selenium, Total (ug/l)	2	5	-----	2	n.d.	4	20[3,5], 5[6]	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	5.4[5]	0	0%
Thallium (ug/l)	3	5	-----	n.d.	n.d.	n.d.	1,400[5], 6.3[8]	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	6	145[5,6]	0	0%
Microcystin, Total (ug/l)	0.05	25	-----	n.d.	n.d.	0.37	20[9]	0	0%
Acetochlor, Total (ug/l)[C]	0.05	15	-----	0.60	n.d.	1.20	-----	-----	-----
Alachlor, Total (ug/l)[C]	0.05	10	0.15	0.18	n.d.	0.24	760[5], 76[6]	0	0%
Atrazine, Total (ug/l)[C]	0.05	25	2.51	1.10	n.d.	21.00	330[5], 12[6]	1	4%
Metolachlor, Total (ug/l)[C]	0.05	25	0.96	0.70	n.d.	4.20	390[5], 100[6]	0	0%
Pesticide Scan (ug/l)[D]	0.05						-----	-----	-----
Acetochlor		5	-----	n.d.	n.d.	1.30	-----	-----	-----
Atrazine		5	3.43	1.70	0.40	10.30	330[5], 12[6]	0	0%
Deethylatrazine		4	-----	0.20	n.d.	1.10	-----	-----	-----
Deisopropylatrazine		4	-----	n.d.	n.d.	0.20	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l microcystins in recreation water for impairment assessment.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Immunoassay analysis.

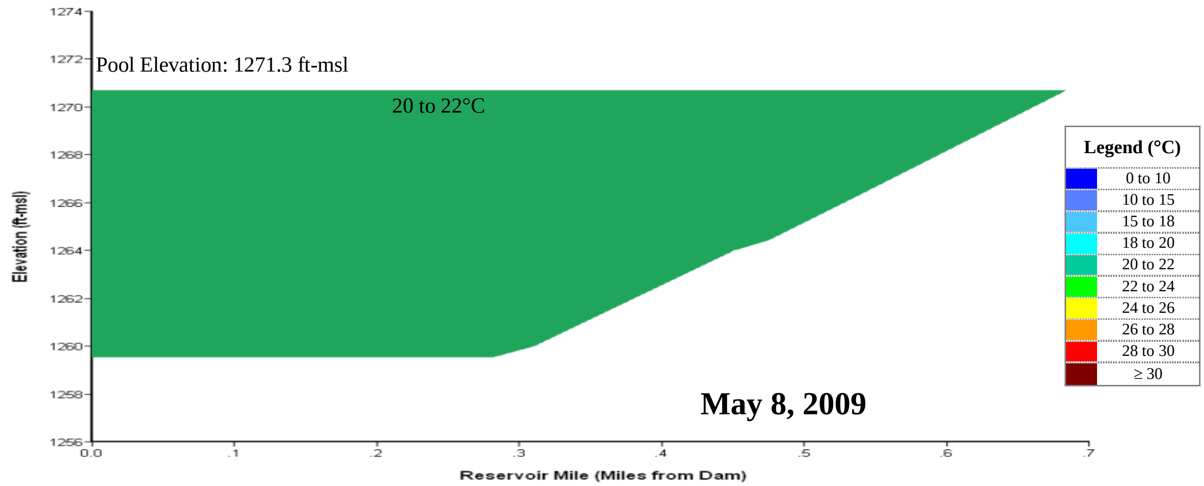
(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

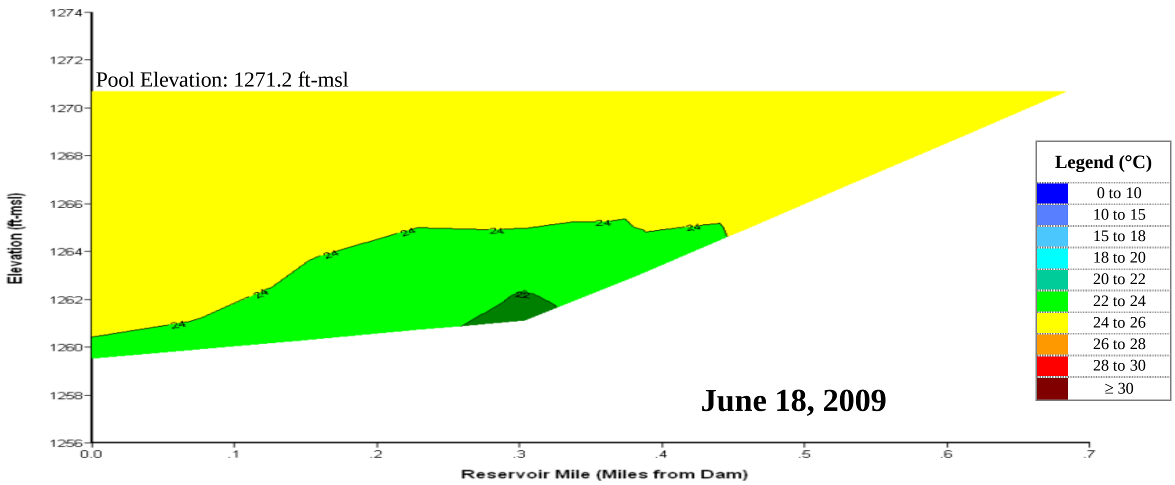
* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 183. Summary of water quality conditions monitored in Stagecoach Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site STGLKML1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, and ORP are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	24	1272.0	1271.0	1270.4	1291.5	-----	-----	-----
Water Temperature (°C)	0.1	166	23.1	23.6	15.0	28.5	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	166	6.7	6.8	1.5	9.7	≥ 5(2)	25	15%
Dissolved Oxygen (% Sat.)	0.1	161	80.2	82.5	18.3	122.4	-----	-----	-----
Specific Conductance (umho/cm)	1	166	388	407	169	490	2,000(3)	0	0%
pH (S.U.)	0.1	166	8.1	8.0	7.1	8.8	≥6.5 & ≤9.0(1)	0	0%
Turbidity (NTUs)	1	160	81	36	3	1301	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	166	352	359	228	498	-----	-----	-----
Secchi Depth (in.)	1	25	17	14	4	46	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	125	18	8	1	78	10(4)	54	43%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).
(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.





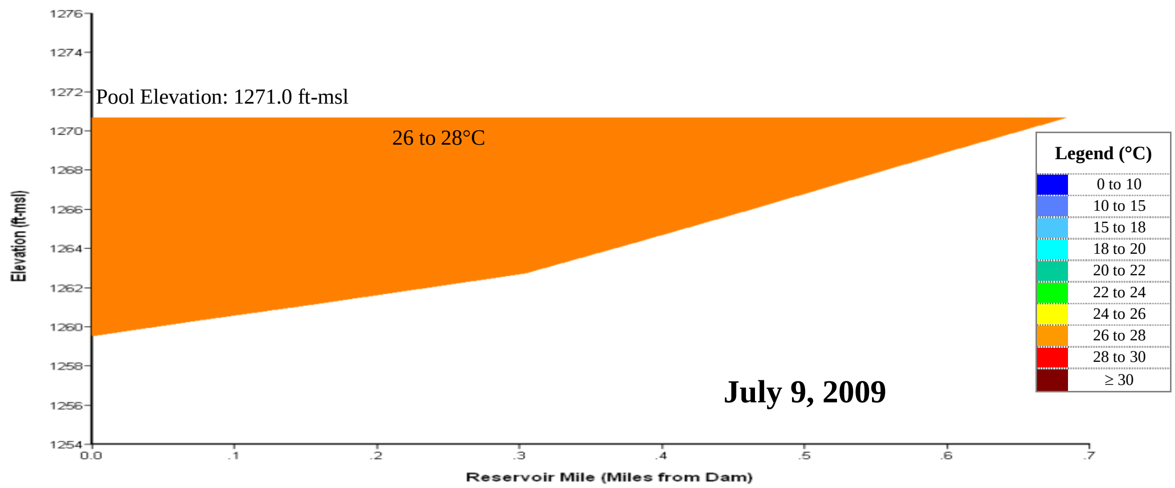
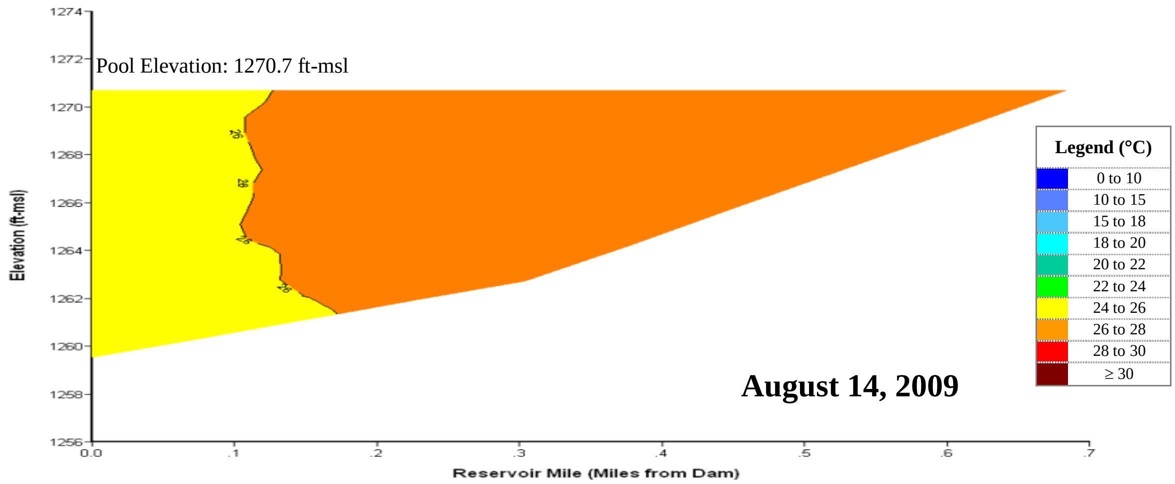


Plate 184. Longitudinal water temperature (°C) contour plots of Stagecoach Reservoir based on depth-profile water temperatures measured at sites STGLKND1 and STGLKML1 in 2009.



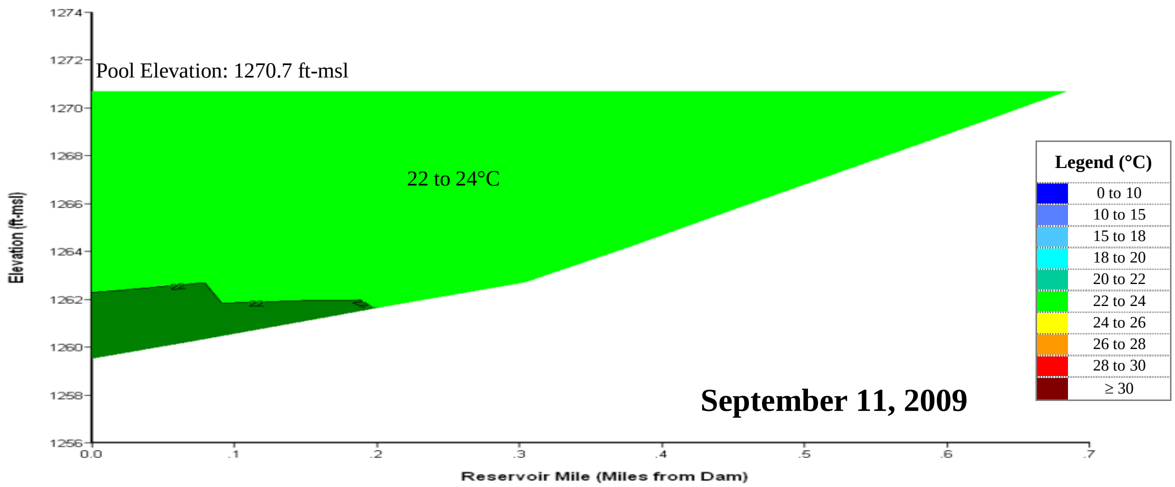


Plate 184. (Continued).

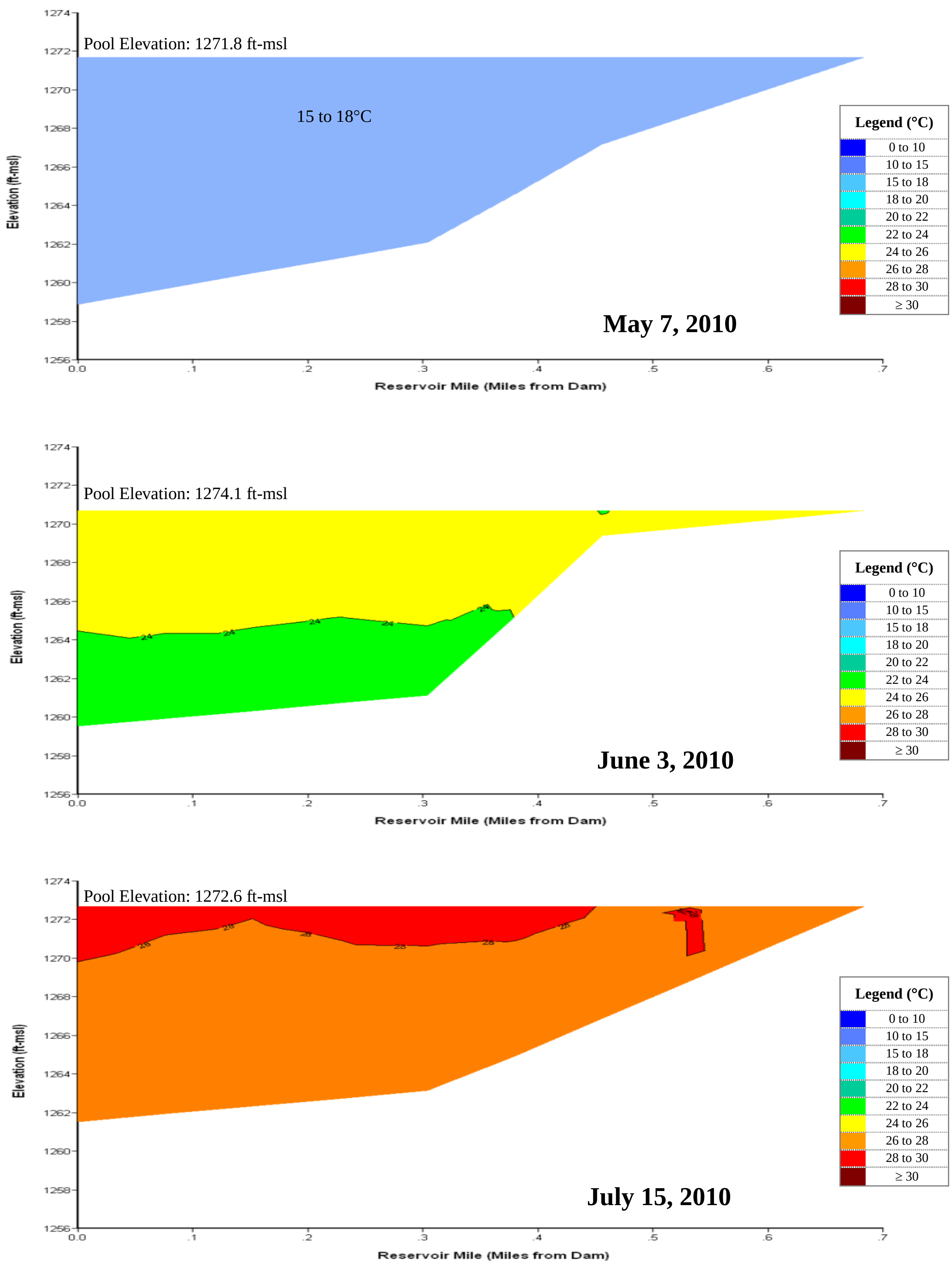
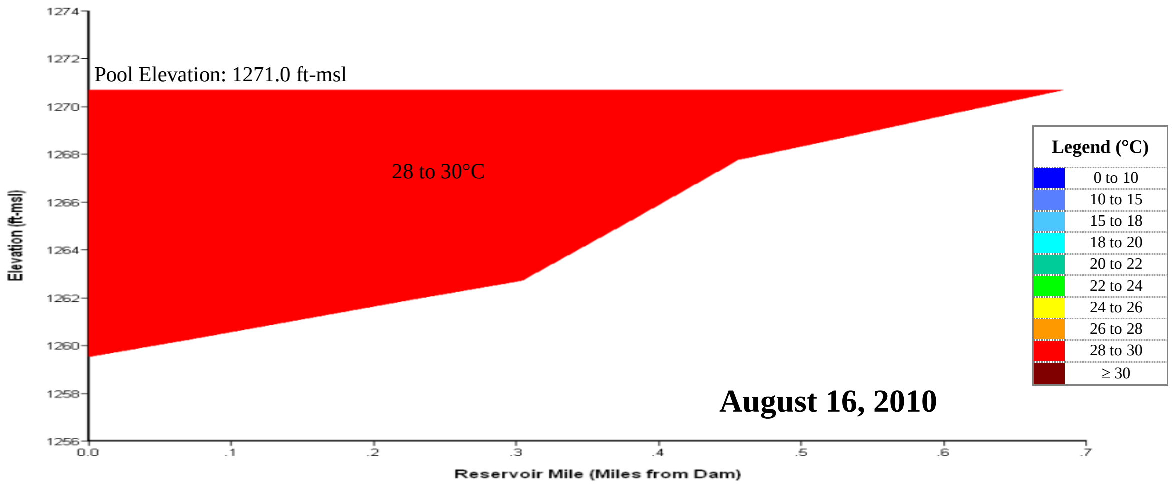


Plate 185. Longitudinal water temperature (°C) contour plots of Stagecoach Reservoir based on depth-profile water temperatures measured at sites STGLKND1, STGLKML1, and STGLKUP1 in 2010.



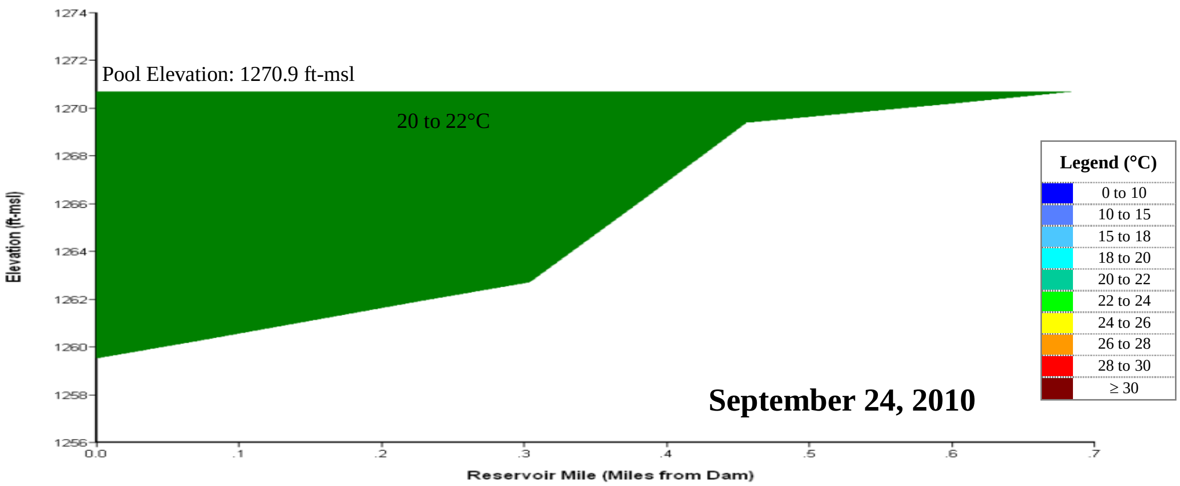


Plate 185. (Continued).

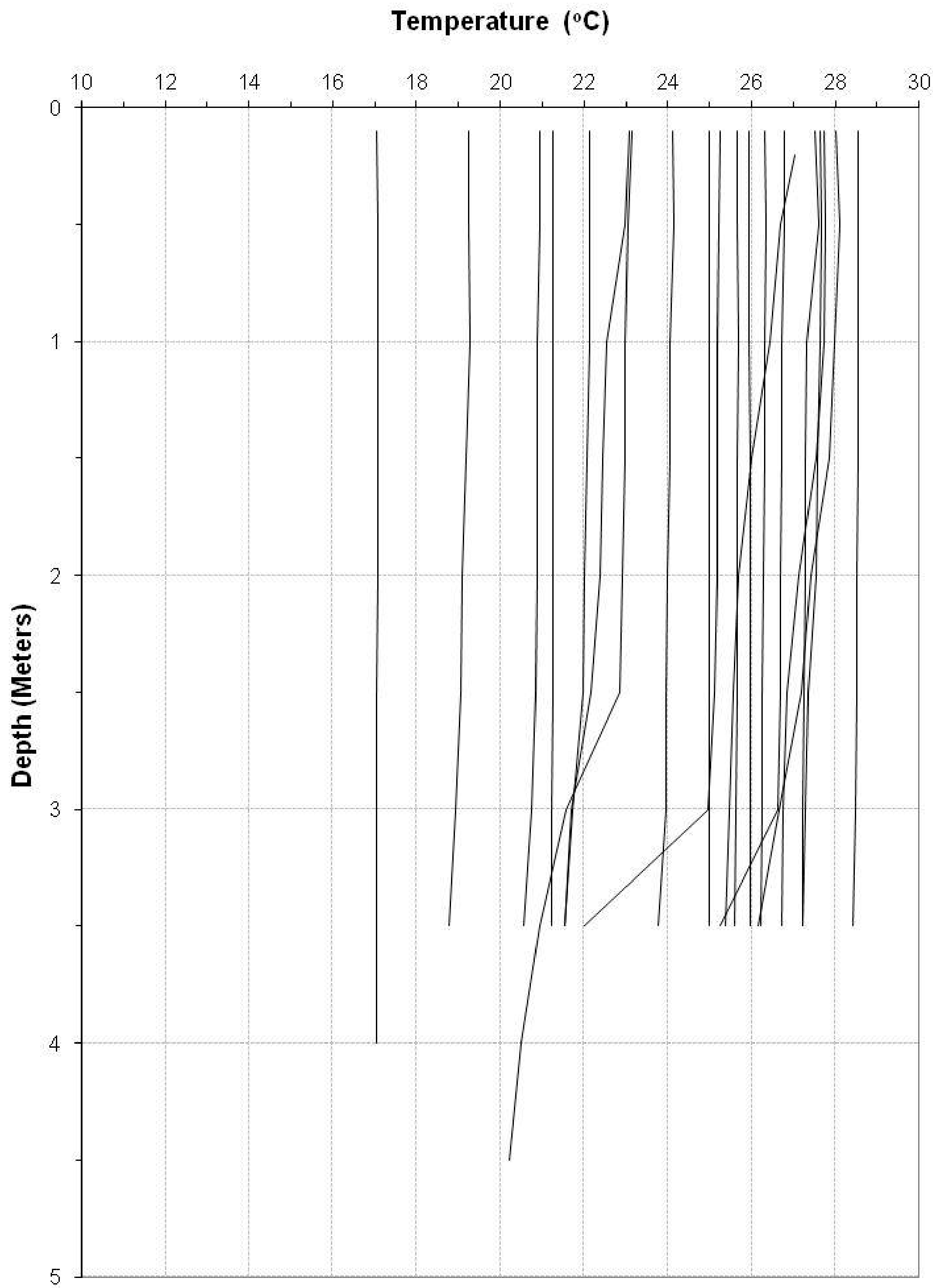


Plate 186. Temperature depth profiles for Stagecoach Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., STGLKND1) during the summer over the 5-year period of 2006 through 2010.

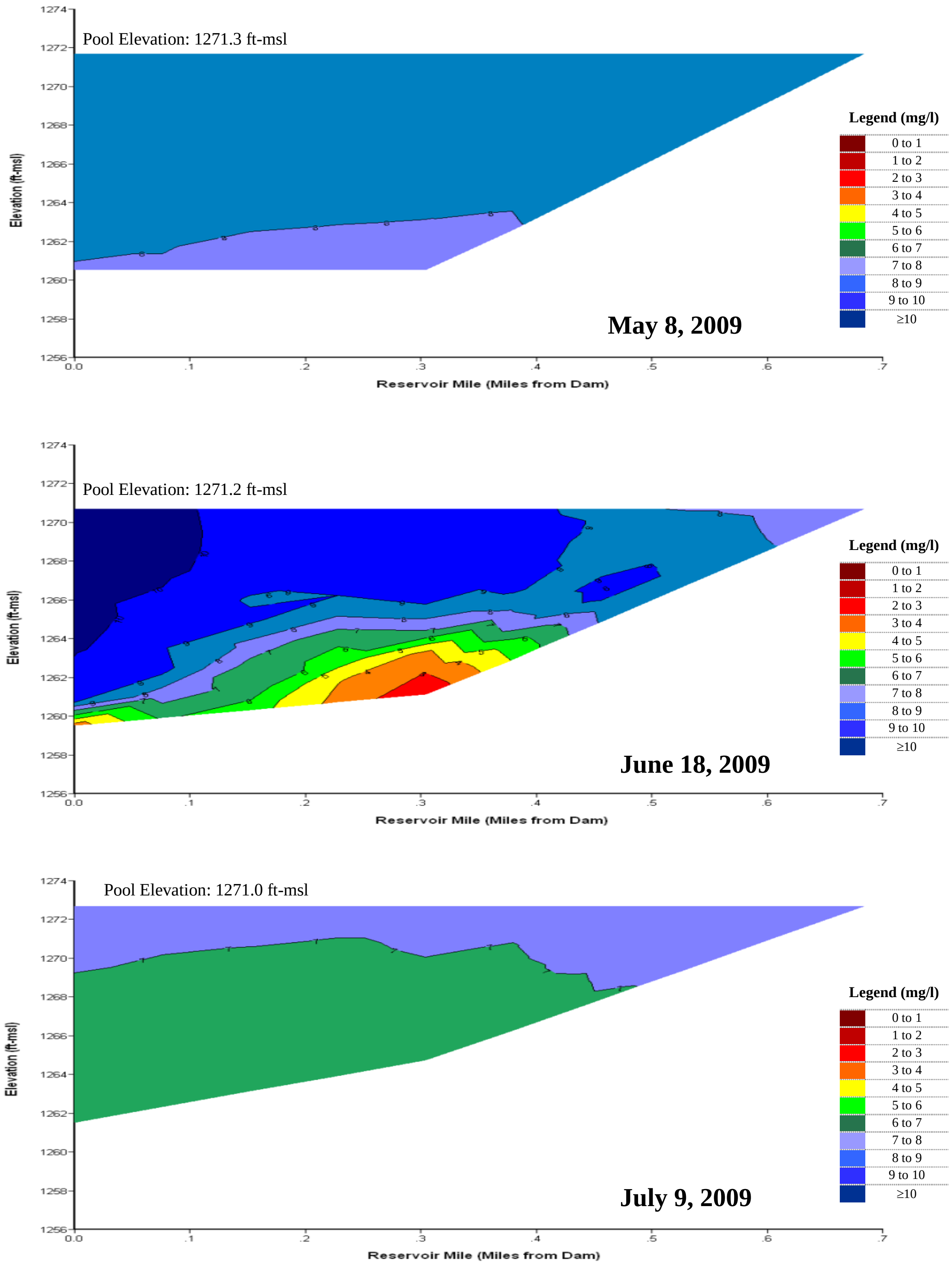
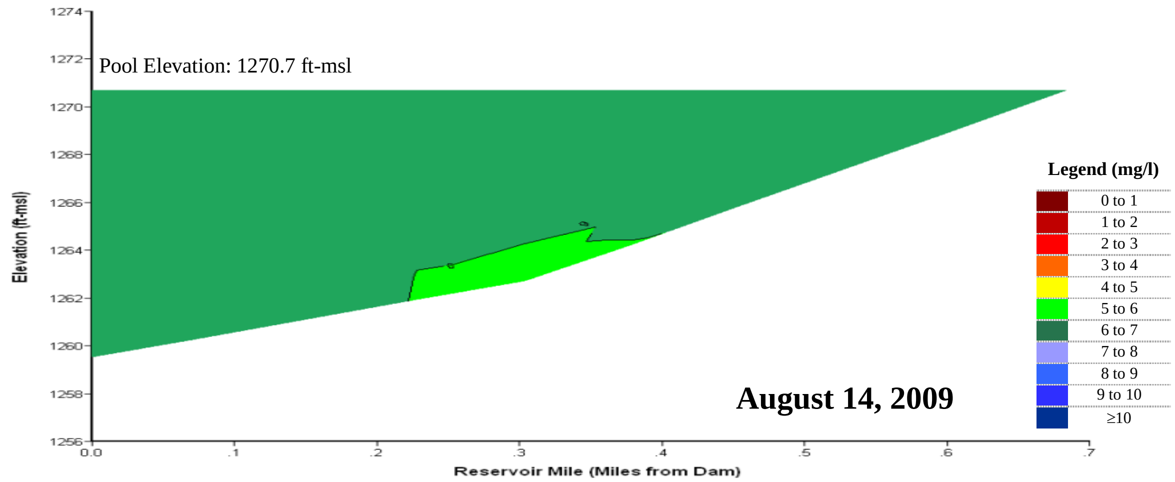


Plate 187. Longitudinal dissolved oxygen (mg/l) contour plots of Stagecoach Reservoir based on depth-profile dissolved oxygen concentrations measured at sites STGLKND1 and STGLKML1 in 2009.



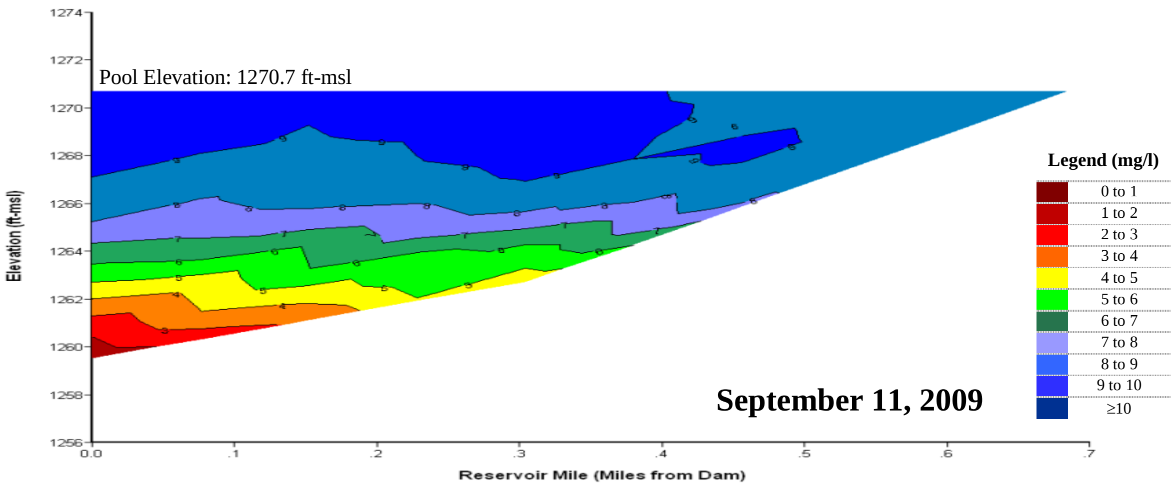


Plate 187. (Continued).

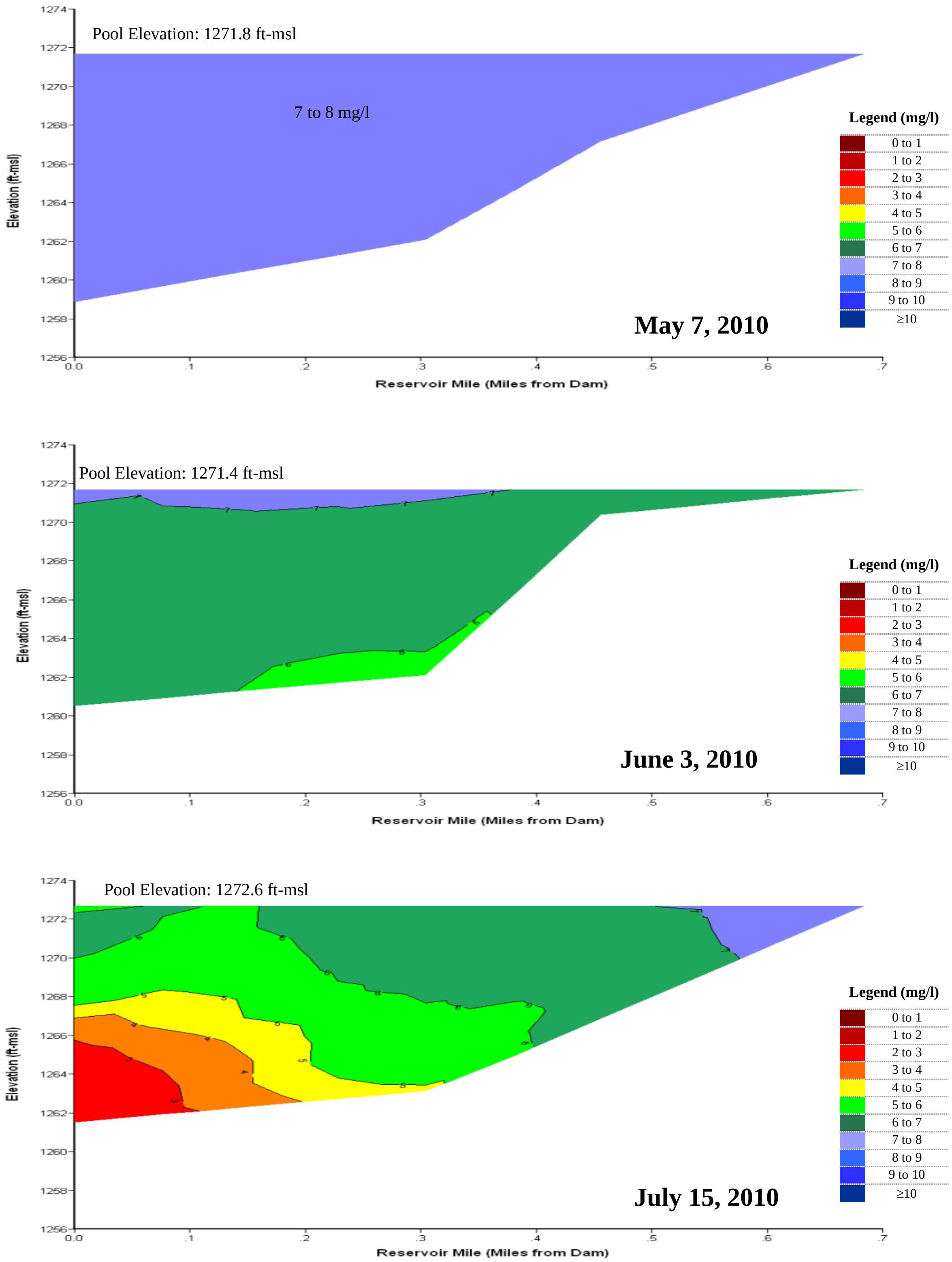
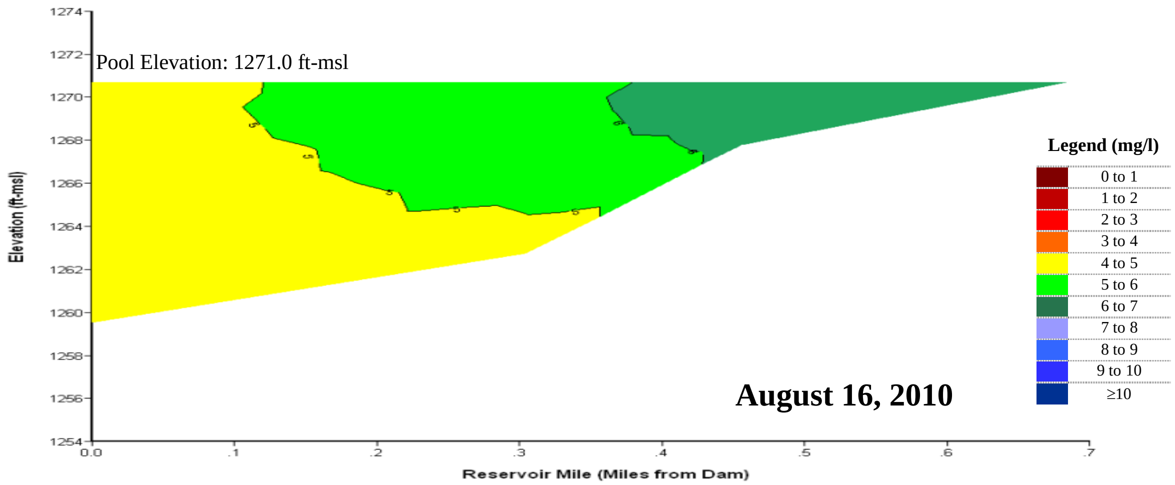


Plate 188. Longitudinal dissolved oxygen (mg/l) contour plots of Stagecoach Reservoir based on depth-profile dissolved oxygen concentrations measured at sites STGLKND1, STGLKML1, and STGLKUP1 in 2010.



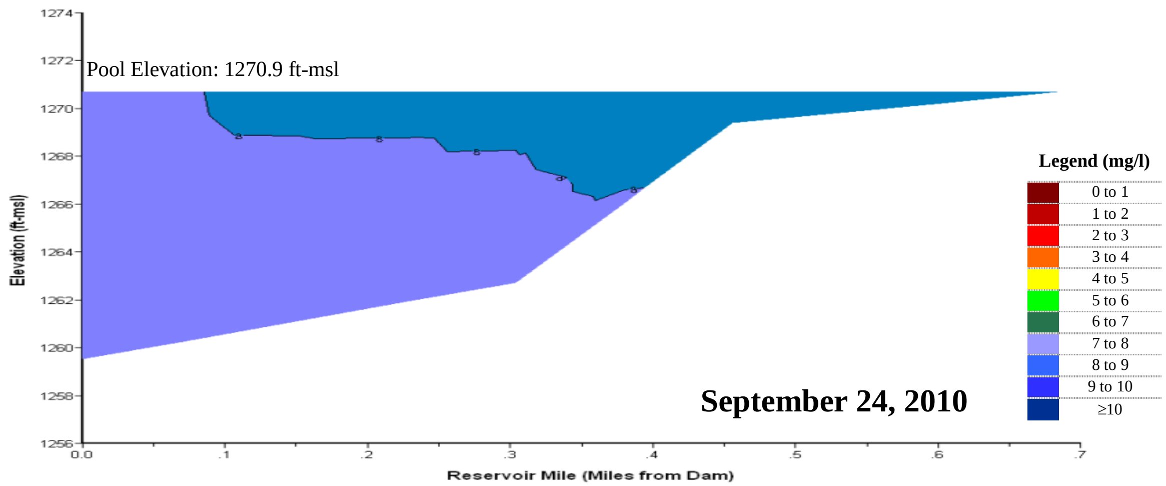


Plate 188. (Continued).

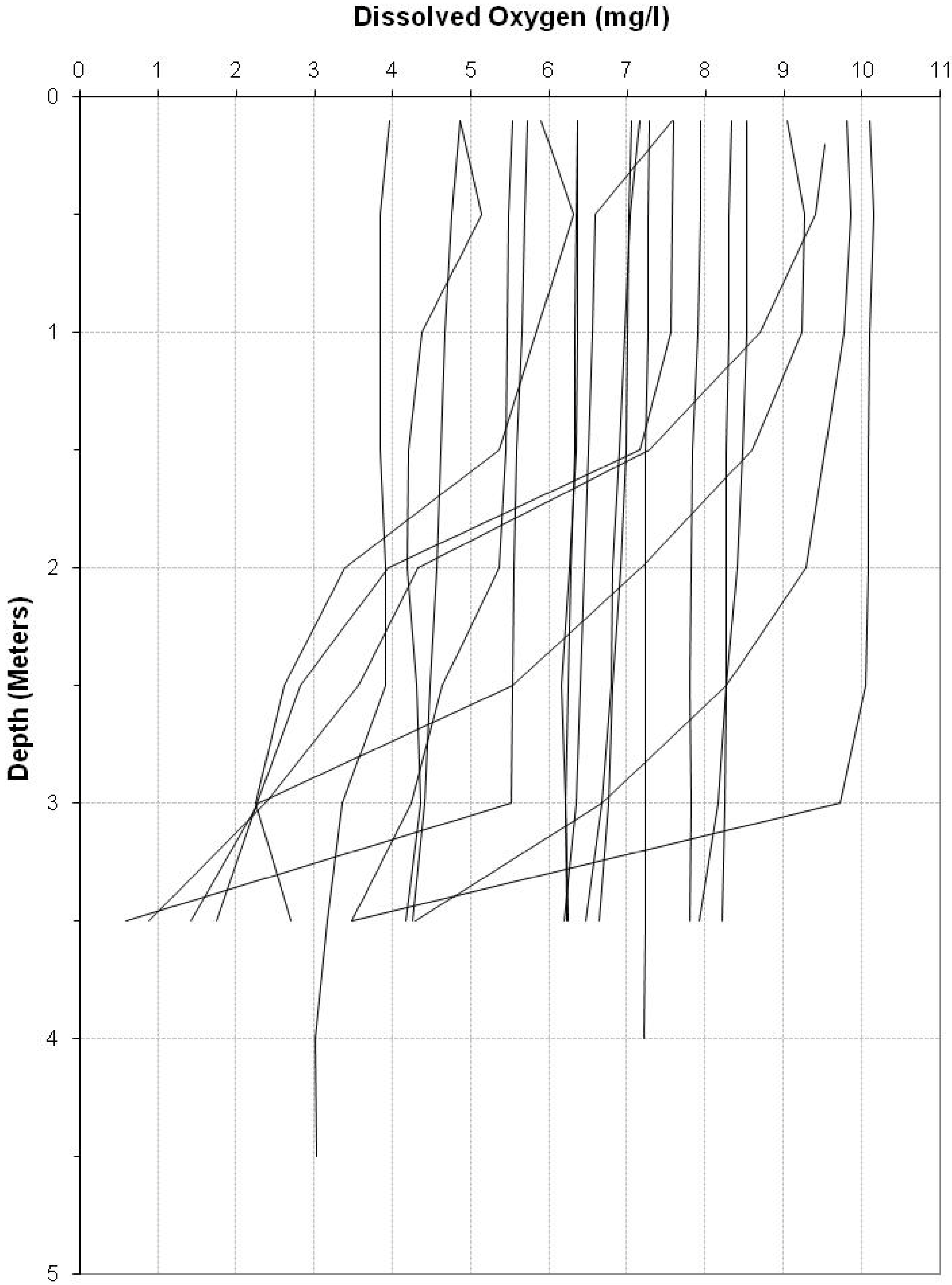


Plate 189. Dissolved oxygen depth profiles for Stagecoach Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., STGLKND1) during the summer over the 5-year period of 2006 through 2010.

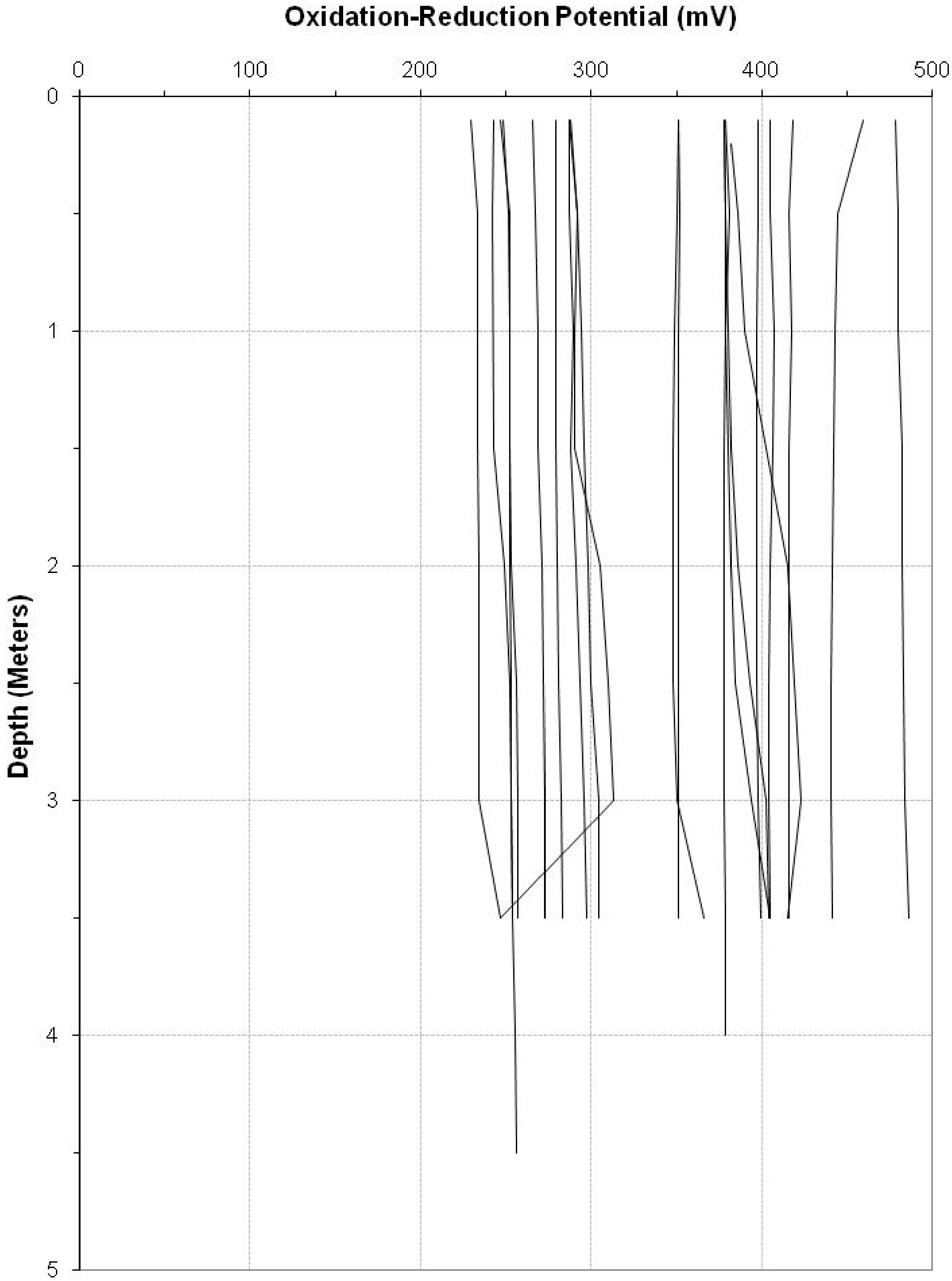


Plate 190. Oxidation-reduction potential depth profiles for Stagecoach Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., STGLKND1) during the summer over the 5-year period of 2006 through 2010.

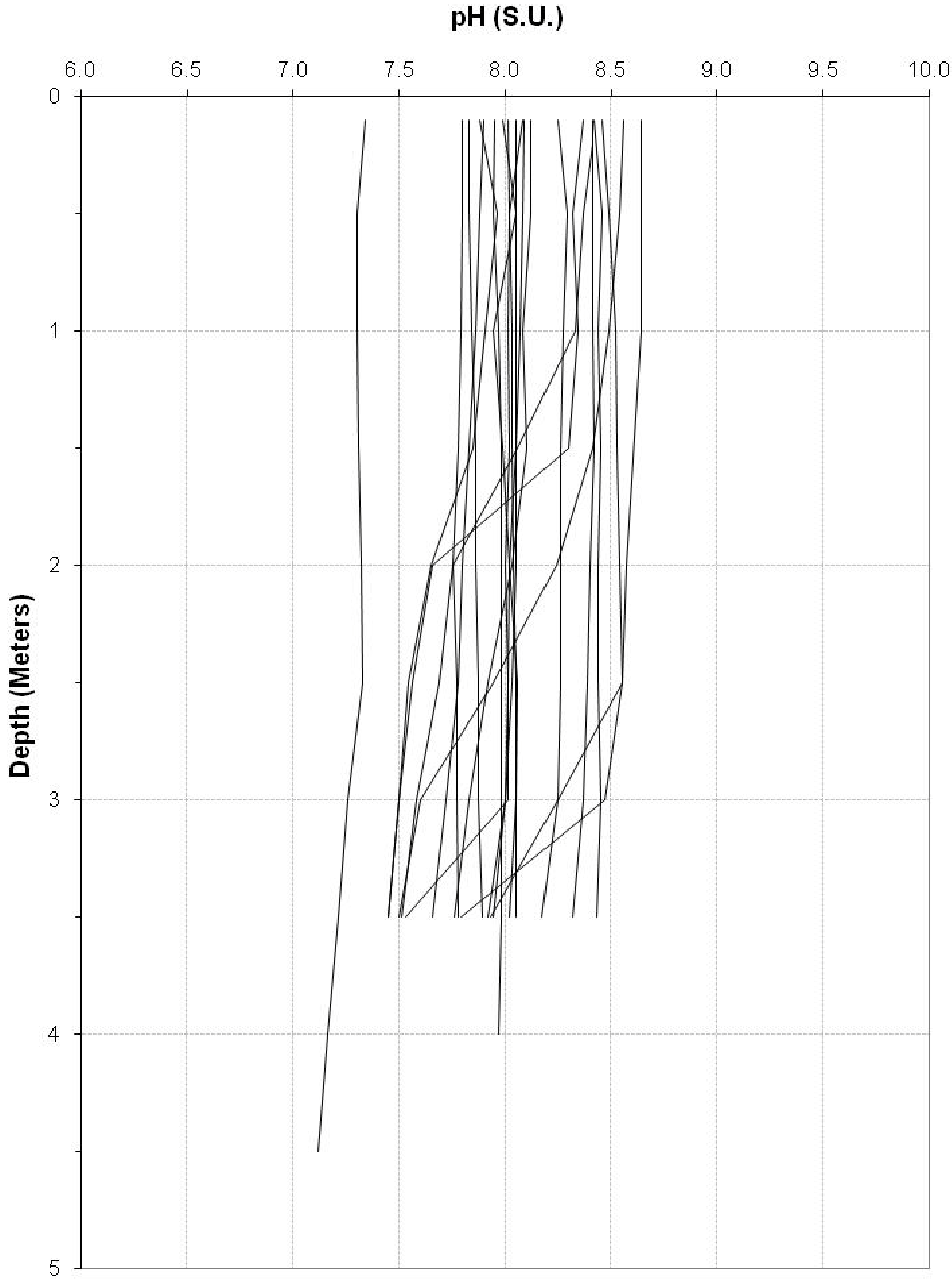


Plate 191. pH depth profiles for Stagecoach Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., STGLKND1) during the summer over the 5-year period of 2006 through 2010.

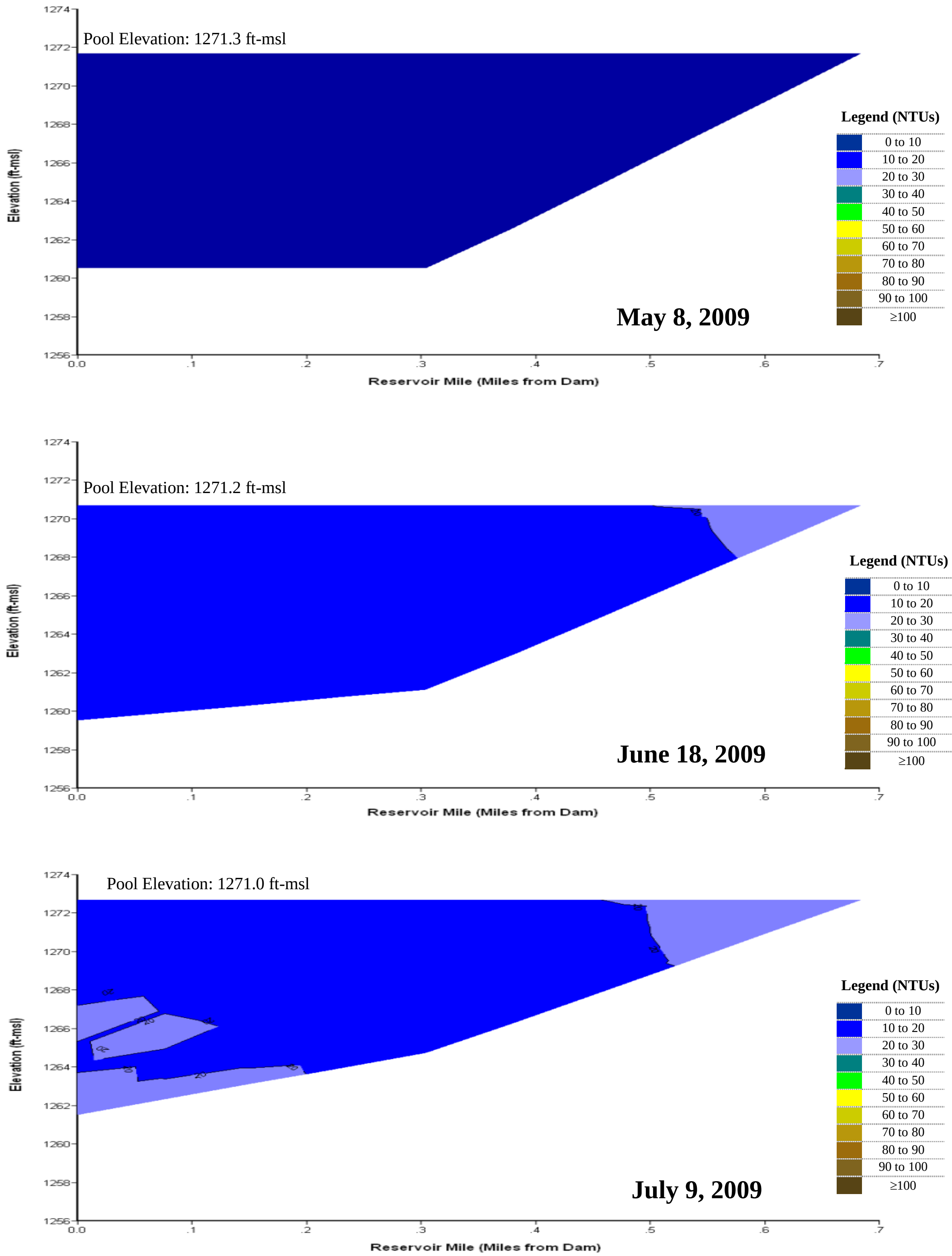
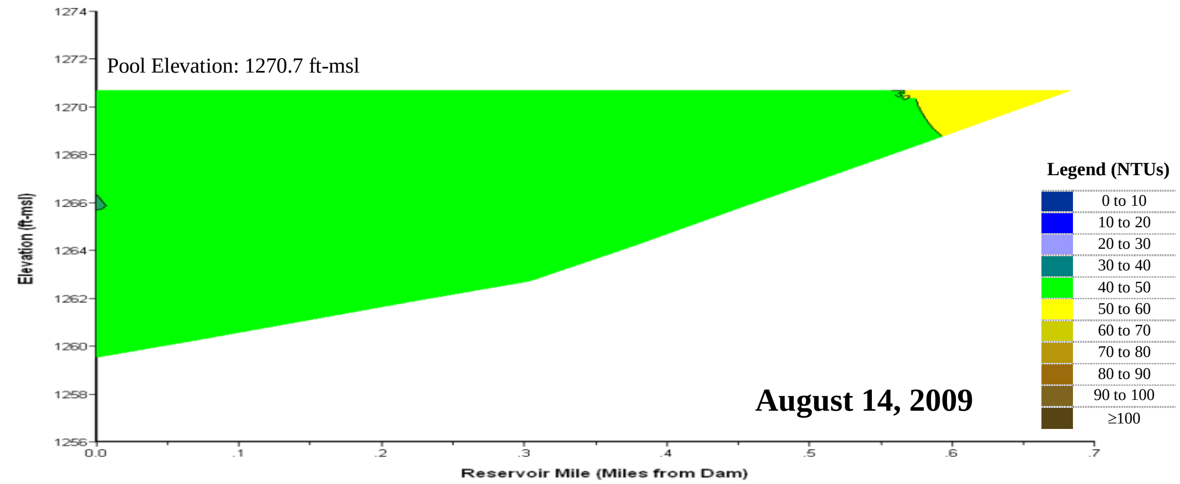


Plate 192. Longitudinal turbidity (NTU) contour plots of Stagecoach Reservoir based on depth-profile turbidity levels measured at sites STGLKND1 and STGLKML1 in 2009.



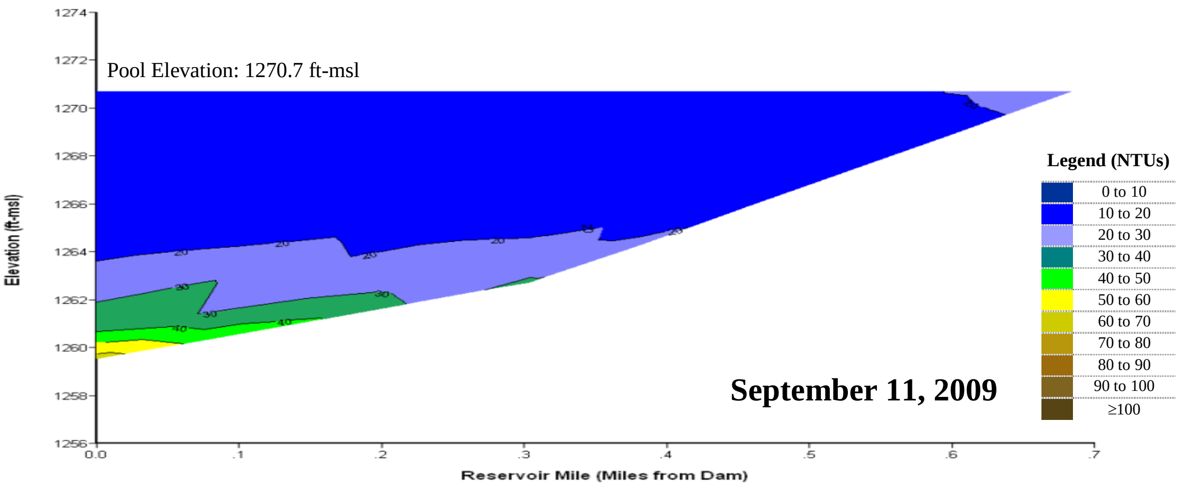
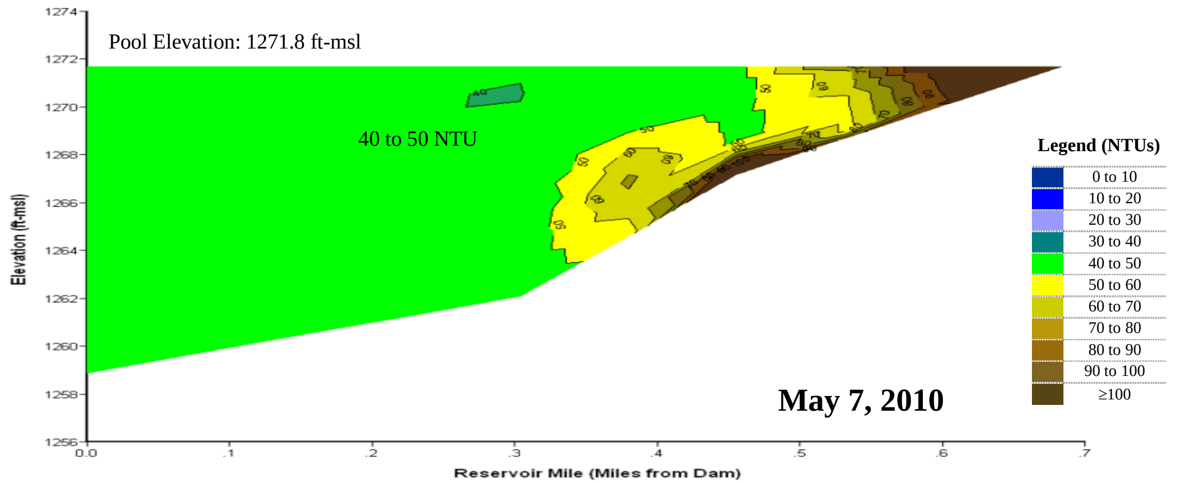
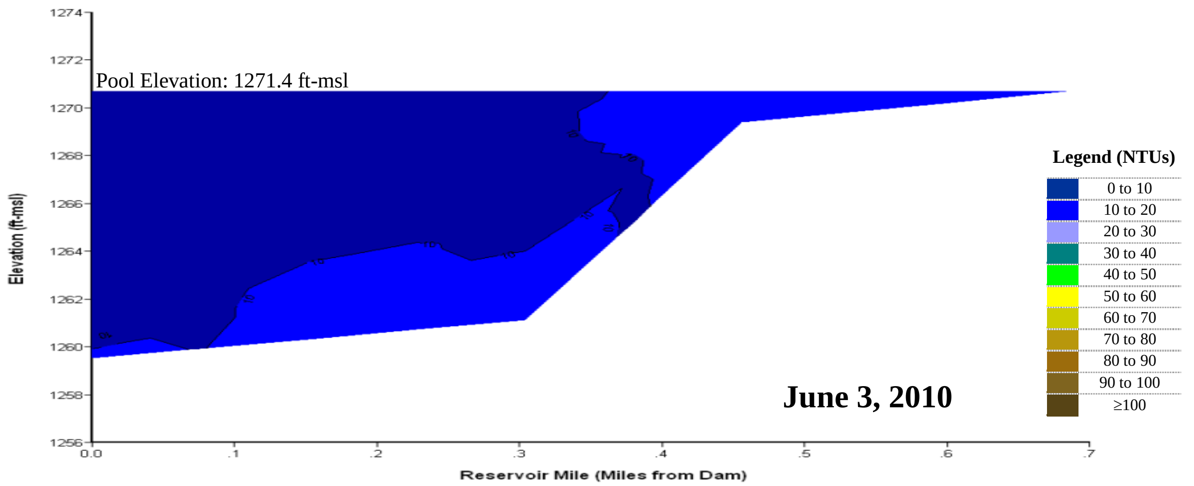


Plate 192. (Continued).





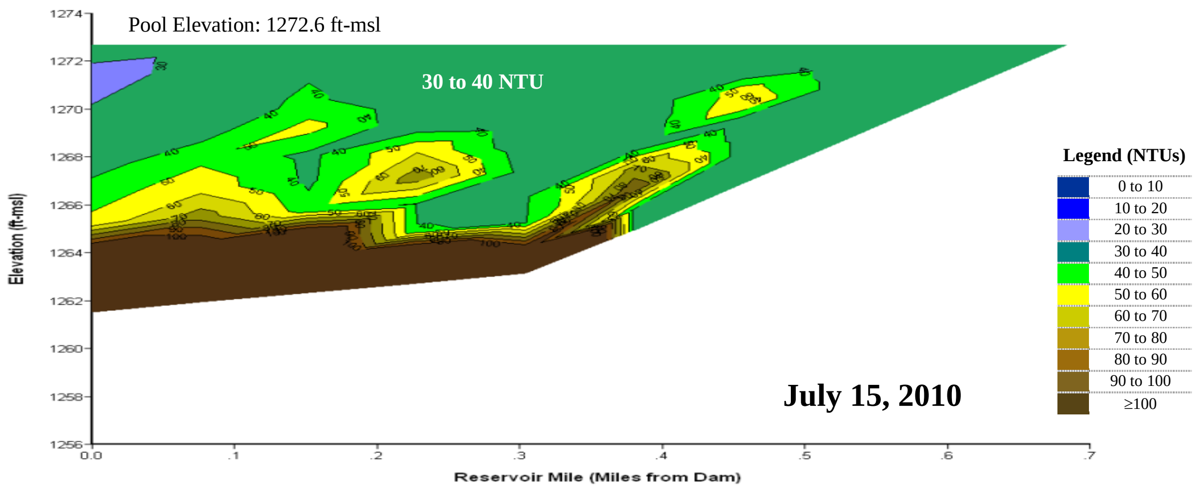
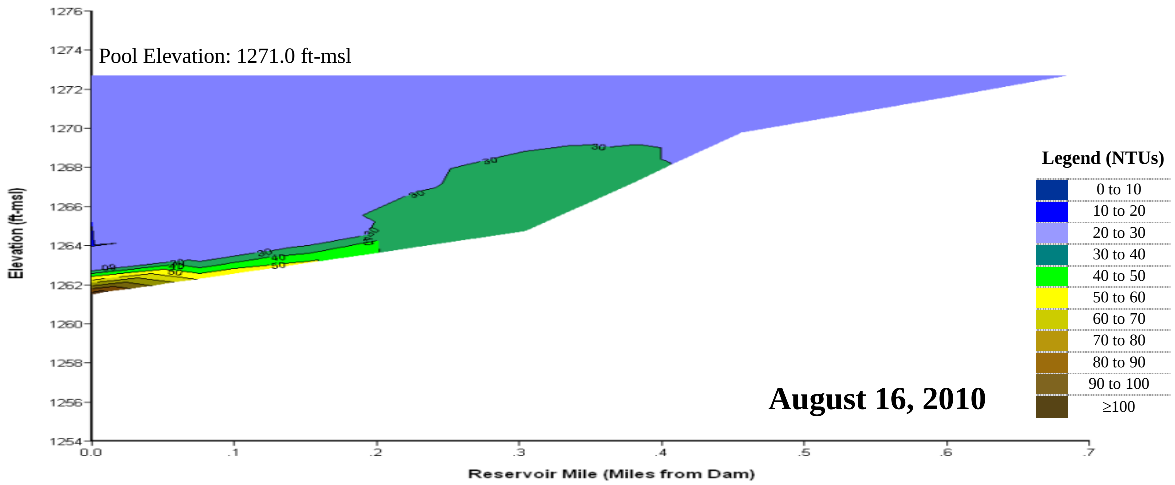


Plate 193. Longitudinal turbidity (NTU) contour plots of Stagecoach Reservoir based on depth-profile turbidity levels measured at sites STGLKND1, STGLKML1, and STGLKUP1 in 2010.



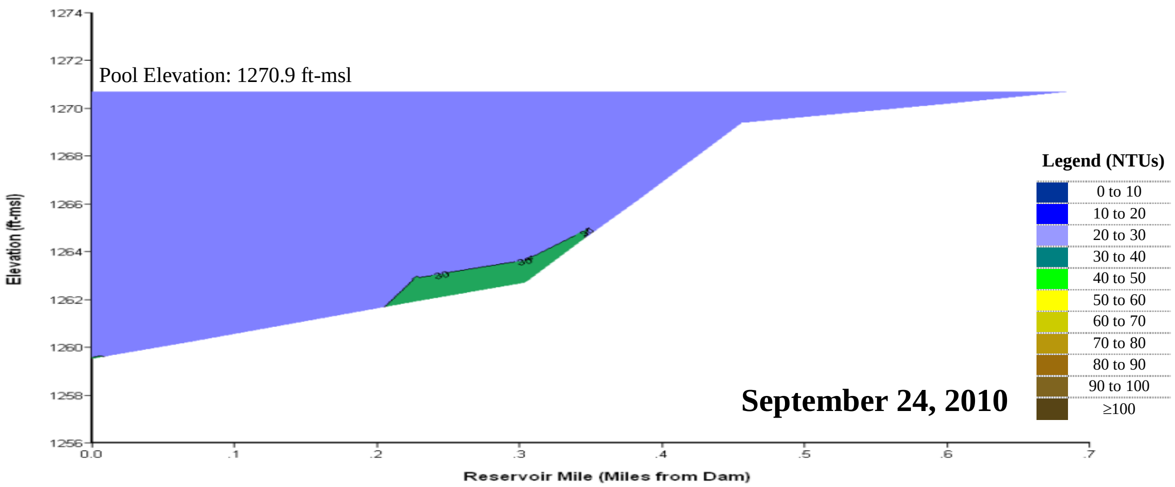


Plate 193. (Continued).

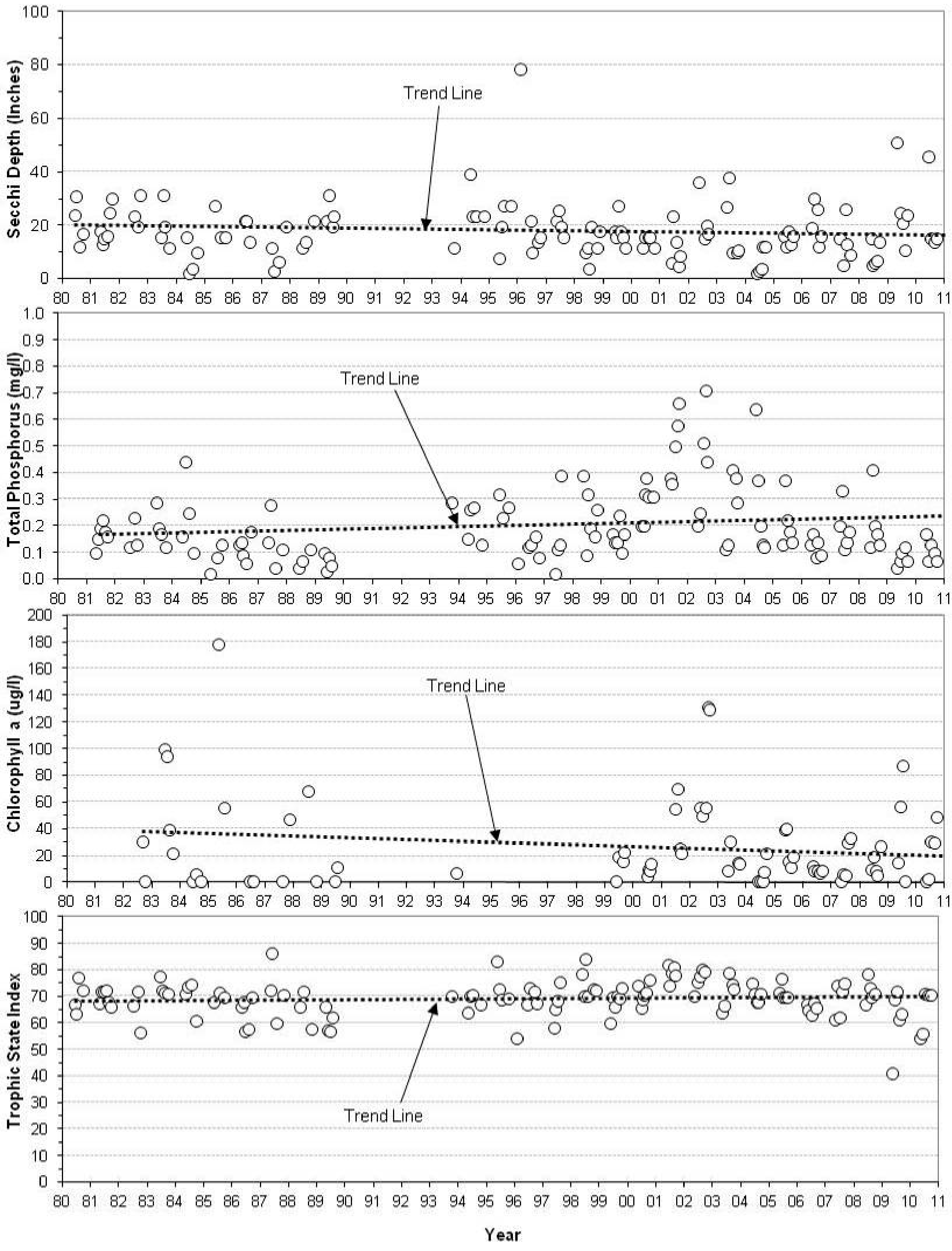


Plate 194. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Stagecoach Reservoir at the near-dam, ambient site (i.e., site STGLKND1) over the 31-year period of 1980 through 2010.

Plate 195. Summary of runoff water quality conditions monitored in the south tributary inflow to Stagecoach Reservoir at monitoring site STGNF1 during the 5-year period 2004 through 2008**.** Runoff conditions have not been monitored since 2008.

	Monitoring Results						Water Quality Standards Attainment		
Parameter	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Kjeldahl N, Total (mg/l)	0.1	8	17.0	3.3	1.2	117.0	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	8	1.61	1.07	0.47	4.94	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	8	1.06	0.90	0.23	2.50	-----	-----	-----
Suspended Solids, Total (mg/l)	4	8	388	266	38	1,030	-----	-----	-----
Acetochlor, Total (ug/l)[C]	0.05	6	3.85	1.87	0.43	11.00	-----	-----	-----
Atrazine, Total (ug/l)[C]	0.05	8	27.91	5.36	0.25	167.50	330[1], 12[2]	0, 2	0%, 25%
Metolachlor, Total (ug/l)[C]	0.05	8	2.32	1.83	n.d.	7.50	390[1], 100[2]	0	0%

n.d. = Not detected.
[A] Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
[B] [1] Acute criterion for aquatic life.
[2] Chronic criterion for aquatic life.
[C] Immunoassay analysis.

Plate 196. Summary of water quality conditions monitored in East Twin Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site ETNLKND1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	24	1340.2	1340.9	1336.7	1342.0	-----	-----	-----
Water Temperature (°C)	0.1	256	23.0	23.8	14.9	31.5	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	256	6.7	7.3	0.2	17.1	≥ 5[2]	50	20%
Dissolved Oxygen (% Sat.)	0.1	248	80.7	86.5	2.0	210.0	-----	-----	-----
Specific Conductance (umho/cm)	1	248	414	412	323	514	2,000[3]	0	0%
pH (S.U.)	0.1	248	8.1	8.1	7.0	9.4	≥6.5 & ≤9.0[1]	7	3%
Turbidity (NTUs)	1	247	23	18	3	119	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	248	307	327	-113	493	-----	-----	-----
Secchi Depth (in.)	1	25	29	26	10	79	-----	-----	-----
Alkalinity, Total (mg/l)	7	50	138	135	100	183	20[1]	0	0%
Ammonia, Total (mg/l)	0.02	50	-----	0.16	0.00	1.72	6.95[4,5], 1.15[4,6]	0, 2	0%, 4%
Chlorophyll *a* (ug/l) – Field Probe	1	204	28	15	2	118	10[7]	133	65%
Chlorophyll *a* (ug/l) – Lab Determined	1	25	31	27	1	83	10[7]	20	80%
Hardness, Total (mg/l)	0.4	5	132.0	129.0	110.0	151.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.10	50	1.6	1.5	0.7	3.3	-----	-----	-----
Nitrogen, Total (mg/)	0.10	50	1.6	1.6	0.7	3.3	1[7]	30	100%
Nitrate-Nitrite N, Total (mg/l)	0.02	50	-----	0.00	n.d.	0.80	100[3]	0	0%
Phosphorus, Total (mg/l)	0.10	50	0.1	0.1	n.d.	0.4	0.05[7]	45	90%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	-----	n.d.	n.d.	0.08	-----	-----	-----
Suspended Solids, Total (mg/l)	4	49	14	12	5	43	-----	-----	-----
Aluminum, Dissolved (ug/l)	25	5	-----	n.d.	n.d.	36	750[5], 87[6]	0	0%
Antimony, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	1	88[5], 30[6]	0	0%
Arsenic, Dissolved (ug/l)	3	5	4	4	3	6	340[5], 16.7[8]	0	0%
Beryllium, Dissolved (ug/l)	3	5	-----	n.d.	n.d.	n.d.	130[5], 5.3[6]	0	0%
Cadmium, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	7.6[5], 0.3[6]	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	2	729[5], 95[6]	0	0%
Copper, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	17[5], 11[6]	0	0%
Lead, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	85[5], 3[6]	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4[5]	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77[6]	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	581[5], 65[6]	0	0%
Selenium, Total (ug/l)	2	5	-----	n.d.	n.d.	6	20[3,5], 5[6]	0, 1	0%, 20%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	5.4[5]	0	0%
Thallium (ug/l)	3	5	-----	n.d.	n.d.	n.d.	1,400[5], 6.3[8]	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	3	145[5,6]	0	0%
Microcystin, Total (ug/l)	0.05	24	-----	n.d.	n.d.	0.58	20[9]	0	0%
Acetochlor, Total (ug/l)[C]	0.05	15	-----	0.70	n.d.	2.20	-----	-----	-----
Alachlor, Total (ug/l)[C]	0.05	9	0.53	0.40	0.20	1.40	760[5], 76[6]	0	0%
Atrazine, Total (ug/l)[C]	0.05	24	1.93	1.95	0.70	4.10	330[5], 12[6]	0	0%
Metolachlor, Total (ug/l)[C]	0.05	24	-----	0.40	n.d.	3.60	390[5], 100[6]	0	0%
Pesticide Scan (ug/l)[D]	0.05						-----	-----	-----
Atrazine		5	-----	1.10	n.d.	2.30	330[5], 12[6]	0	0%
Deethylatrazine		4	-----	0.50	n.d.	0.70	-----	-----	-----
Metolachlor		5	-----	n.d.	n.d.	1.20	390[5], 100[6]	0	0%

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l microcystins in recreation water for impairment assessment.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Immunoassay analysis.

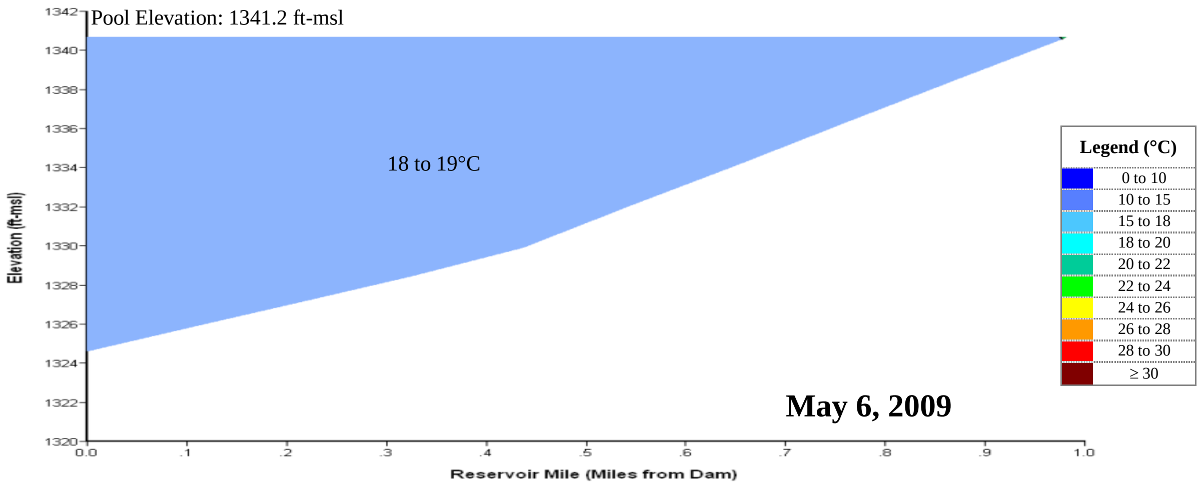
(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

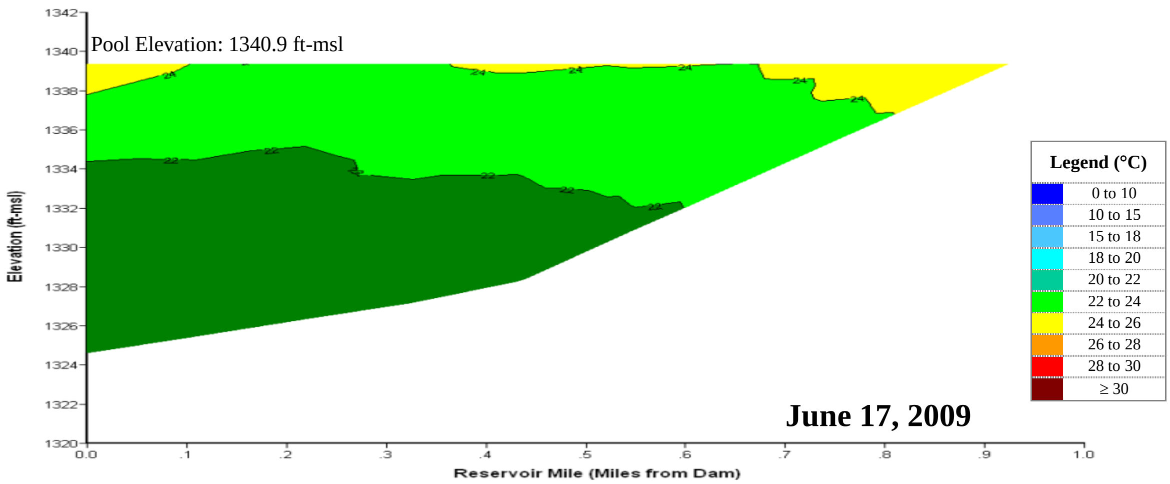
* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 197. Summary of water quality conditions monitored in East Twin Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site ETNLKML1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, and ORP are for water column profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	20	1340.6	1340.9	1336.7	1342.0	-----	-----	-----
Water Temperature (°C)	0.1	184	23.5	24.5	16.2	30.9	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	183	7.8	7.7	0.3	14.6	≥ 5[2]	13	7%
Dissolved Oxygen (% Sat.)	0.1	183	95.2	94.9	3.9	179.7	-----	-----	-----
Specific Conductance (umho/cm)	1	184	412	415	323	512	2,000[3]	0	0%
pH (S.U.)	0.1	184	8.3	8.3	7.3	9.3	≥6.5 & ≤9.0[1]	7	4%
Turbidity (NTUs)	1	183	24	20	3	100	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	184	322	336	-69	476	-----	-----	-----
Secchi Depth (in.)	1	22	25	22	8	49	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	168	32	16	1	132	10[4]	121	72%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).
(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.





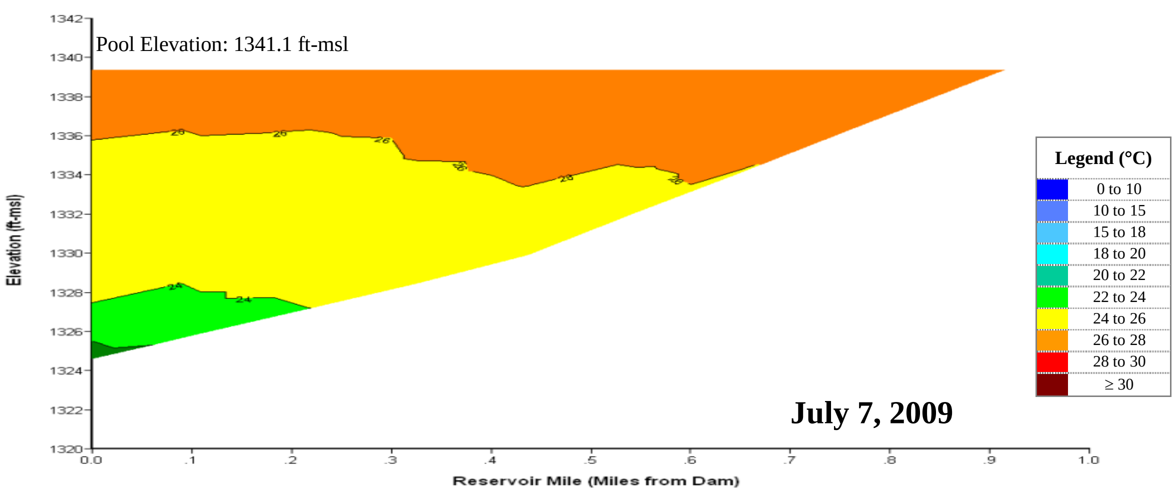
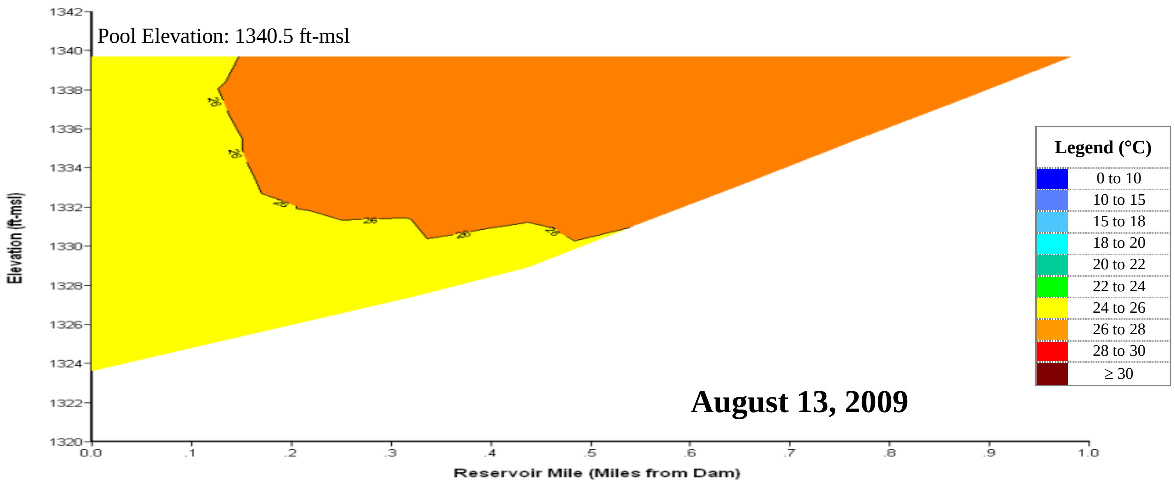


Plate 198. Longitudinal water temperature (°C) contour plots of East Twin Reservoir based on depth-profile water temperatures measured at sites ETNLKND1 and ETNLKML1 in 2009.



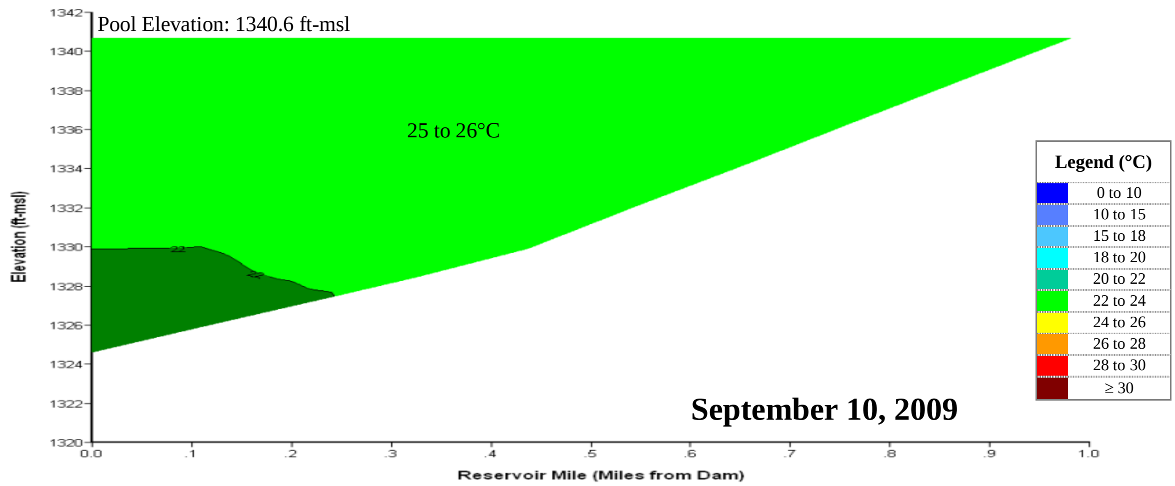


Plate 198. (Continued).

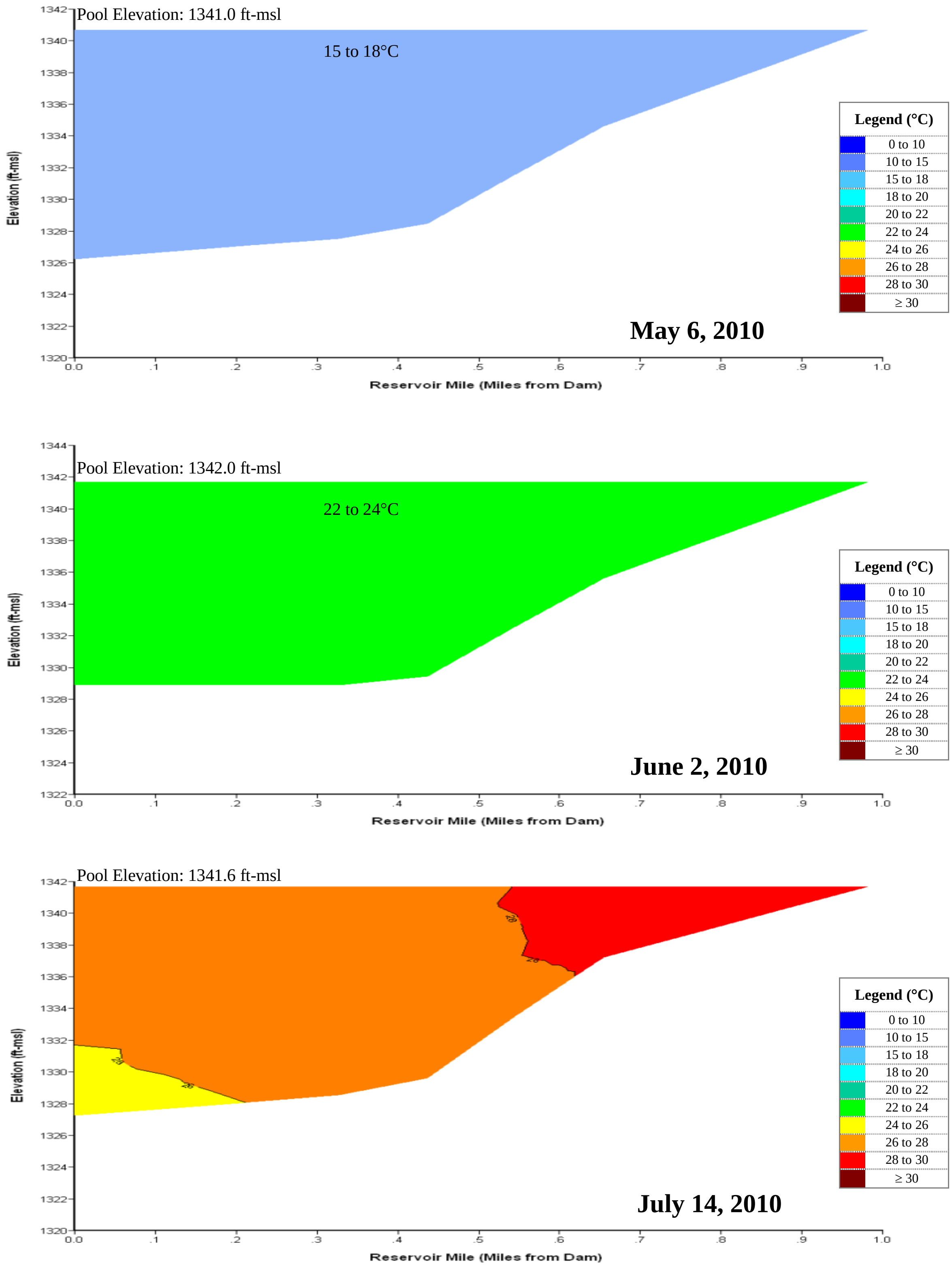
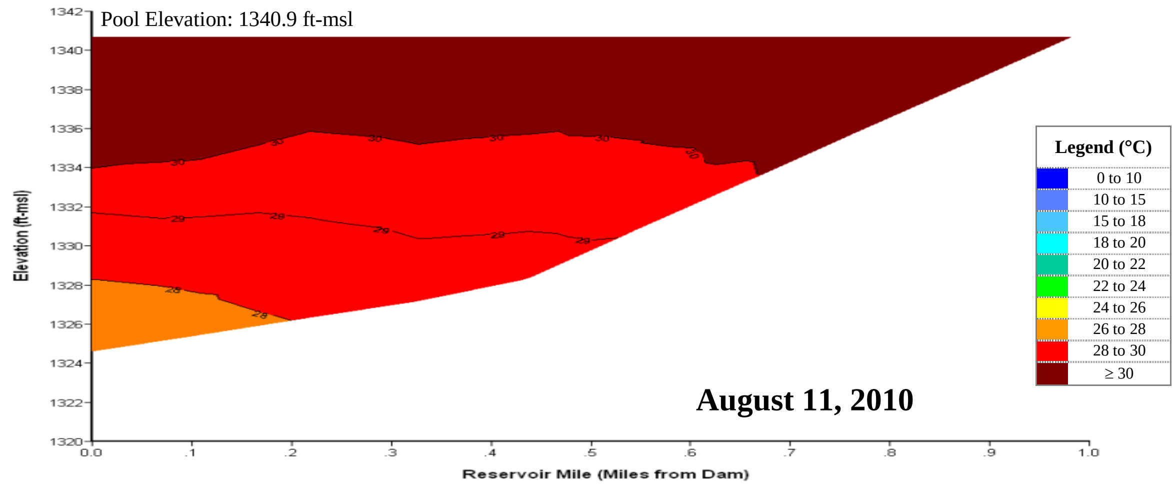


Plate 199. Longitudinal water temperature (°C) contour plots of East Twin Reservoir based on depth-profile water temperatures measured at sites ETNLKND1, ETNLKML1, and ETNLKUP1 in 2010.



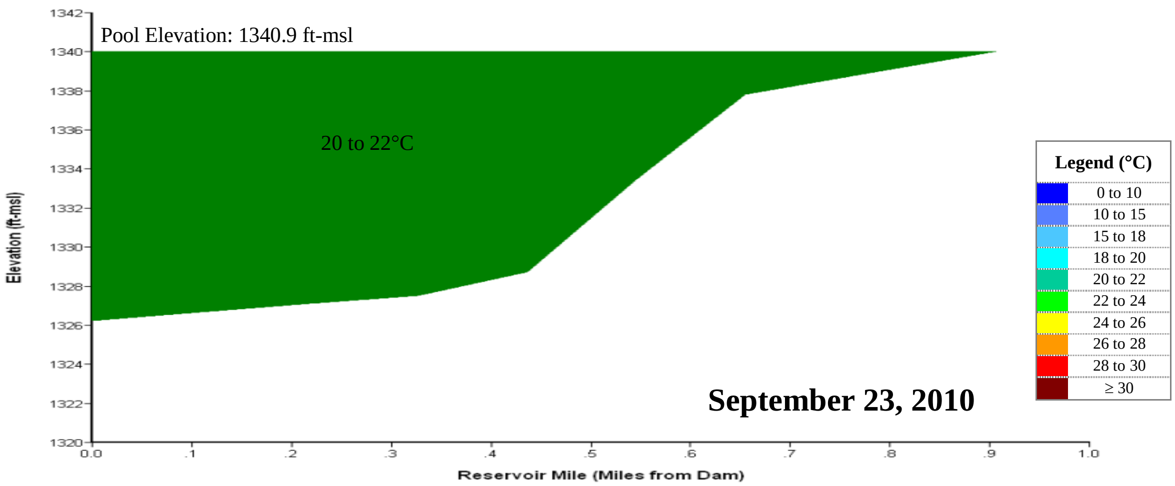


Plate 199. (Continued).

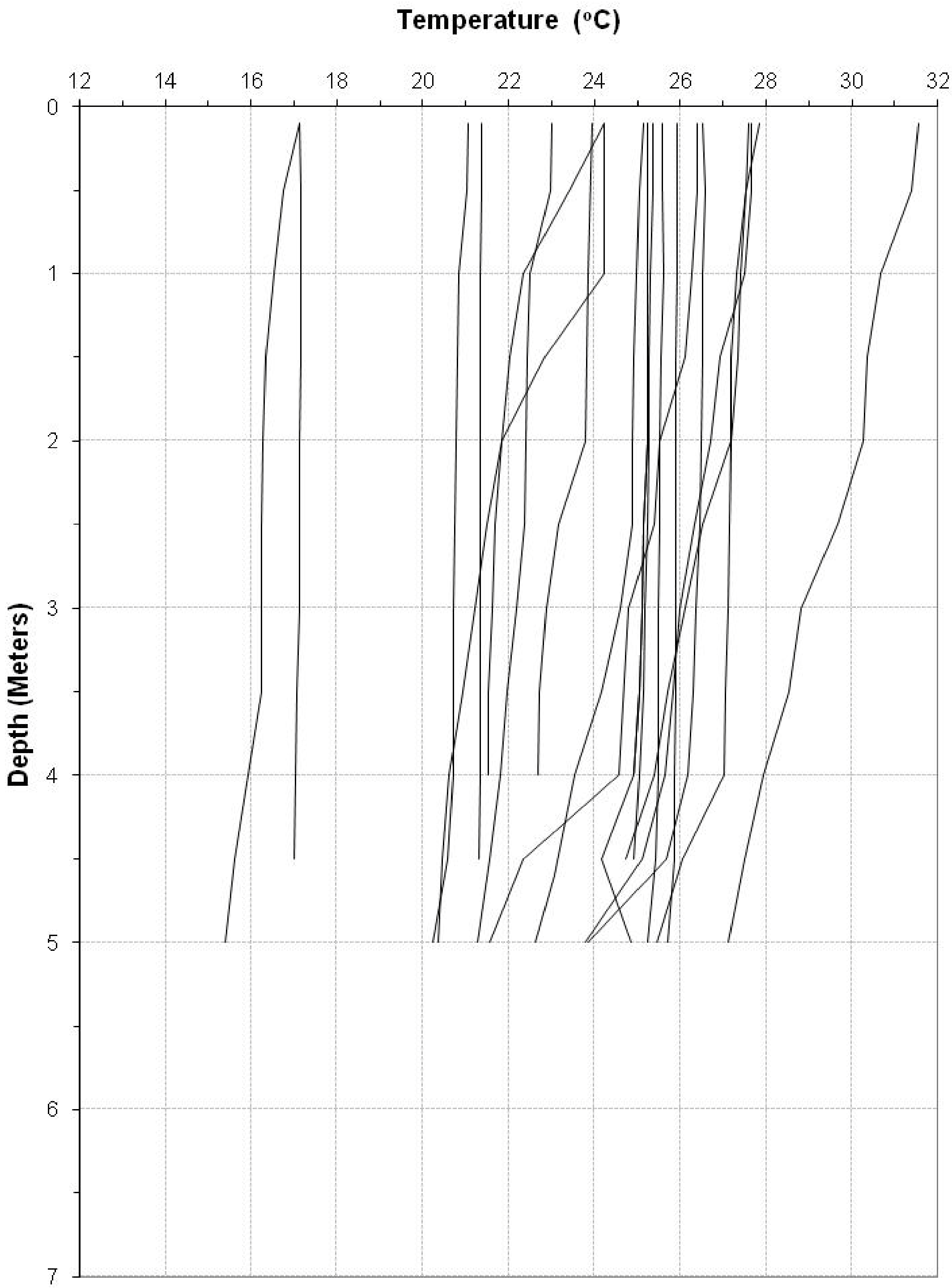


Plate 200. Temperature depth profiles for East Twin Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., ETNLKND1) during the summer over the 5-year period of 2006 through 2010.

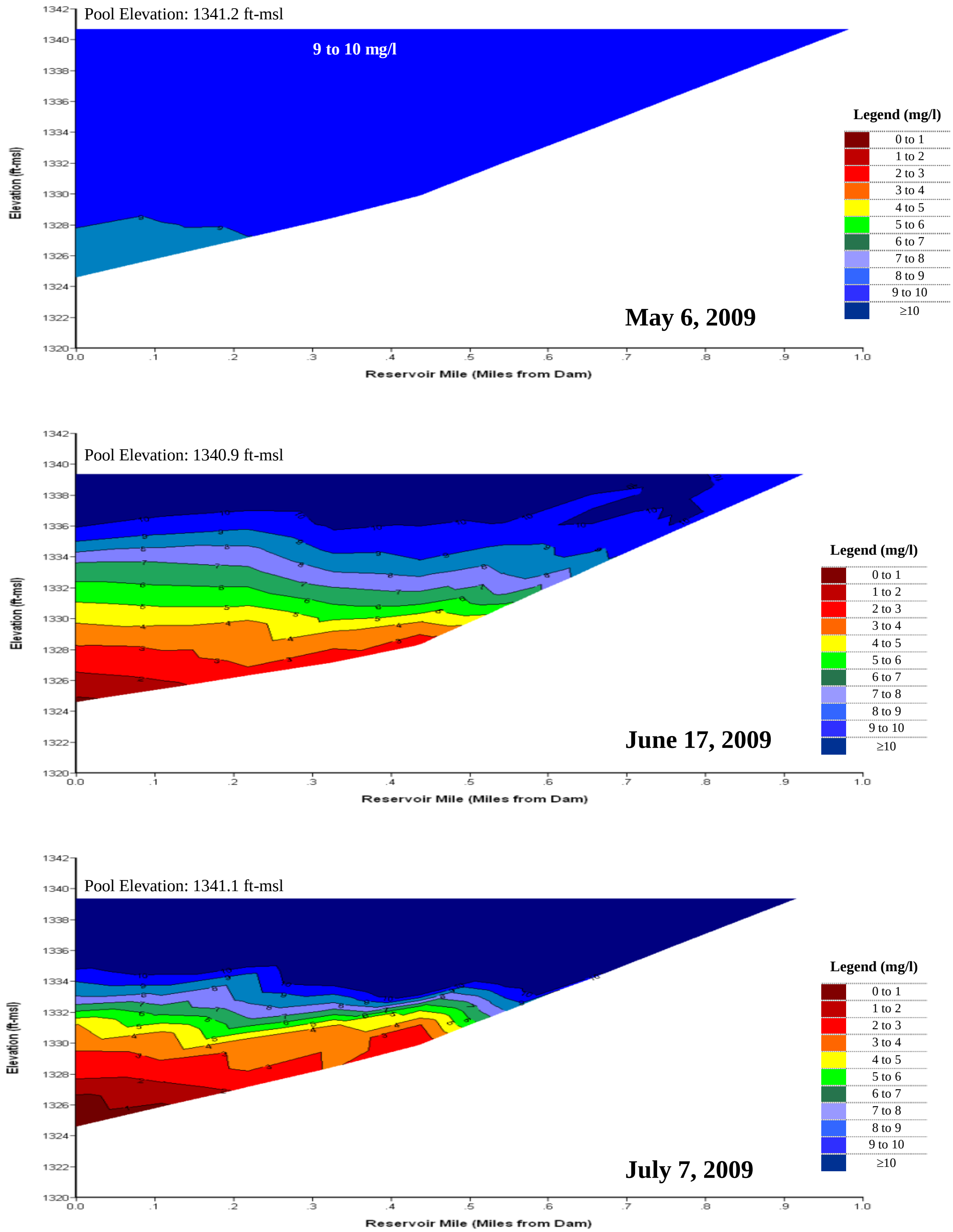
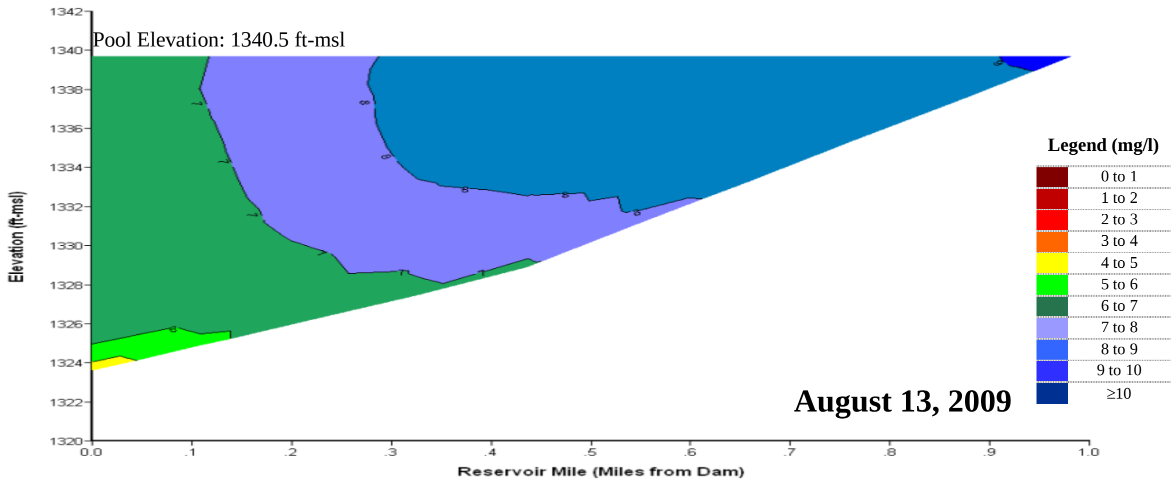


Plate 201. Longitudinal dissolved oxygen (mg/l) contour plots of East Twin Reservoir based on depth-profile dissolved oxygen concentrations measured at sites ETNLKND1 and ETNLKML1 in 2009.



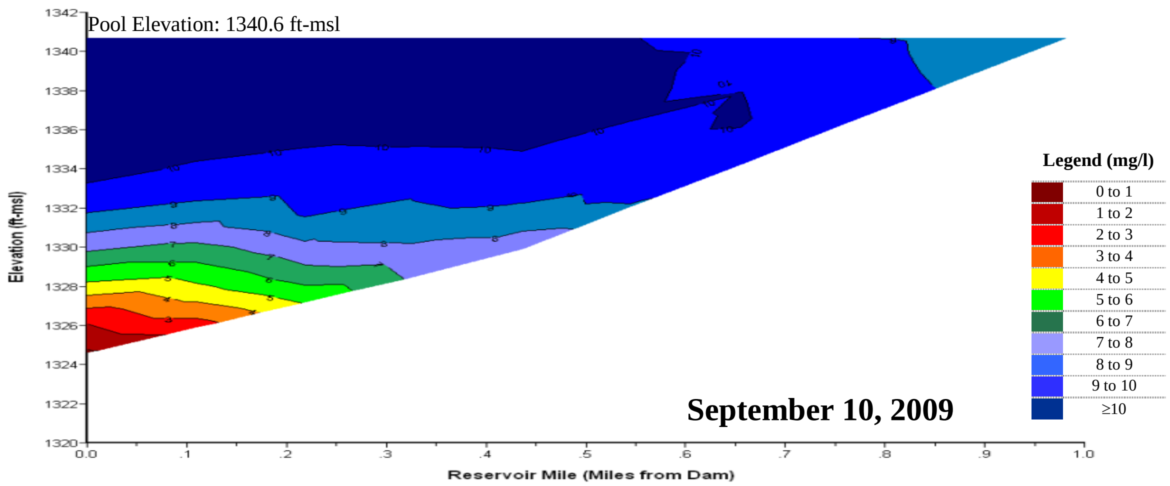


Plate 201. (Continued).

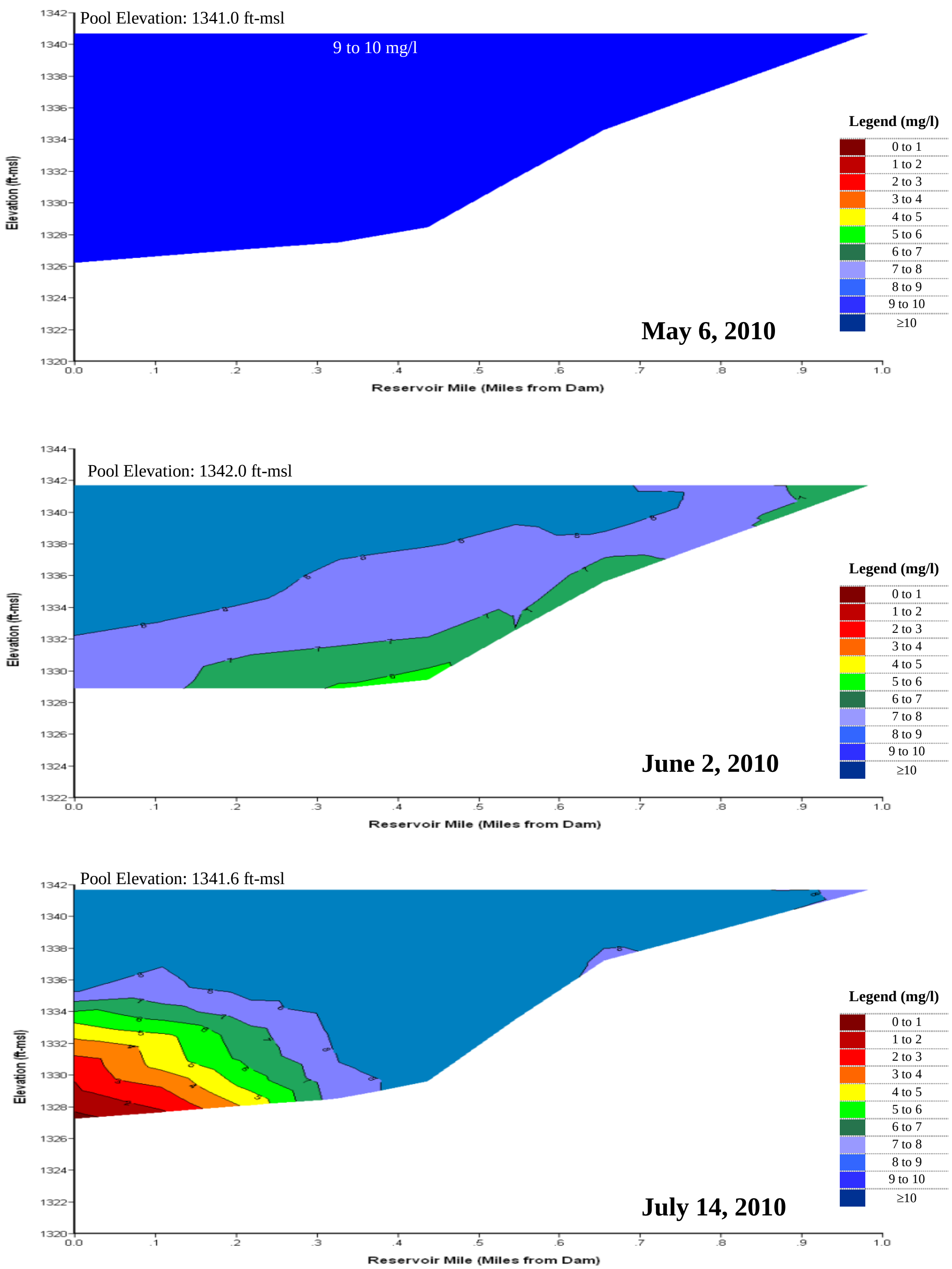
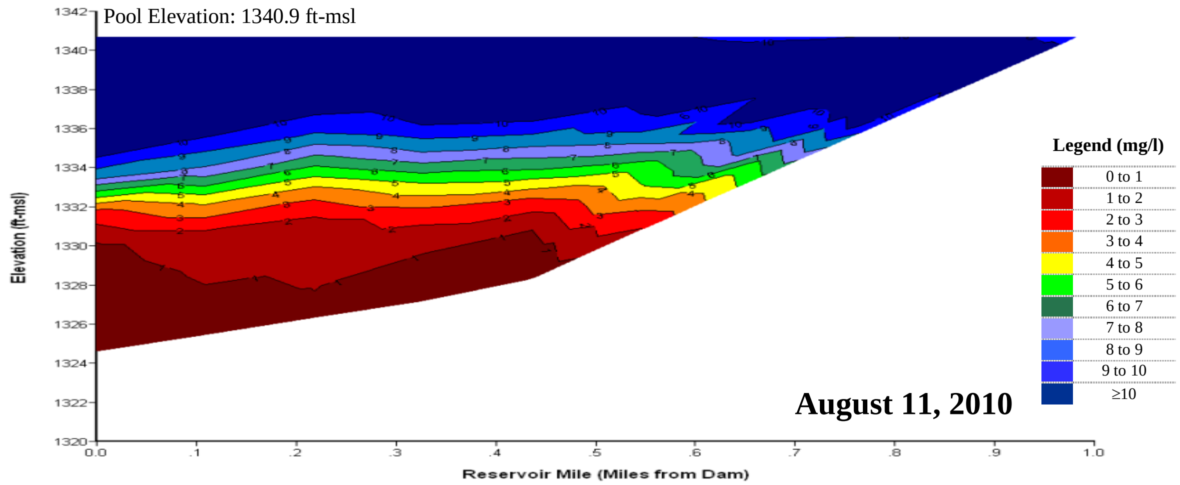


Plate 202. Longitudinal dissolved oxygen (mg/l) contour plots of East Twin Reservoir based on depth-profile dissolved oxygen concentrations measured at sites ETNLKND1, ETNLKML1, and ETNLKUP1 in 2010.



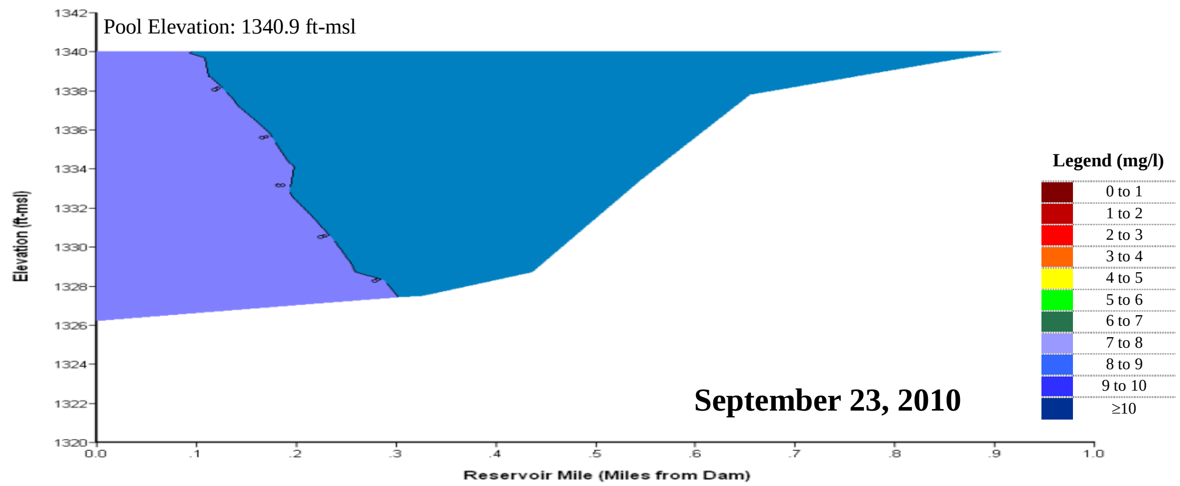


Plate 202. (Continued).

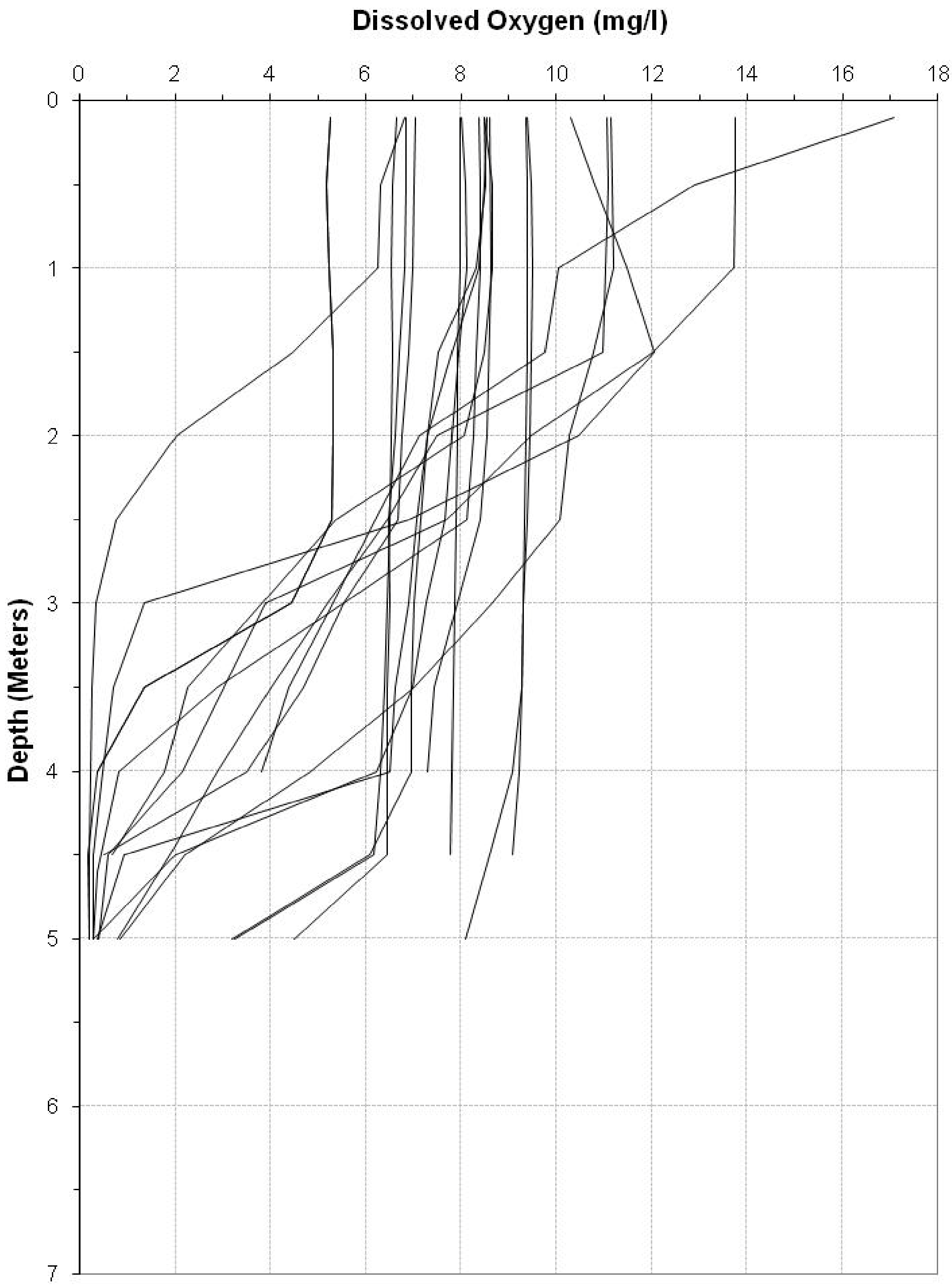


Plate 203. Dissolved oxygen depth profiles for East Twin Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., ETNLKND1) during the summer over the 5-year period of 2006 through 2010.

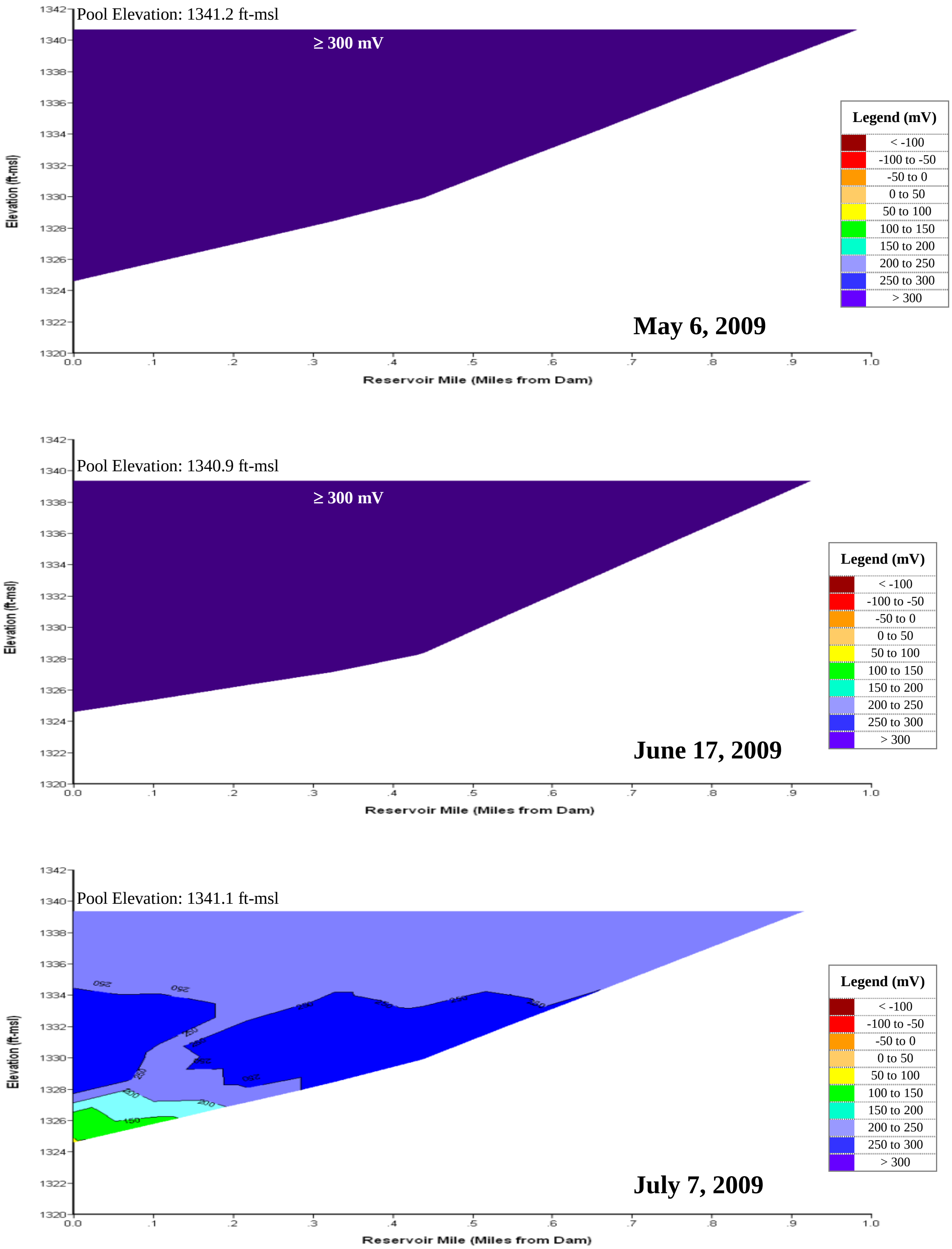
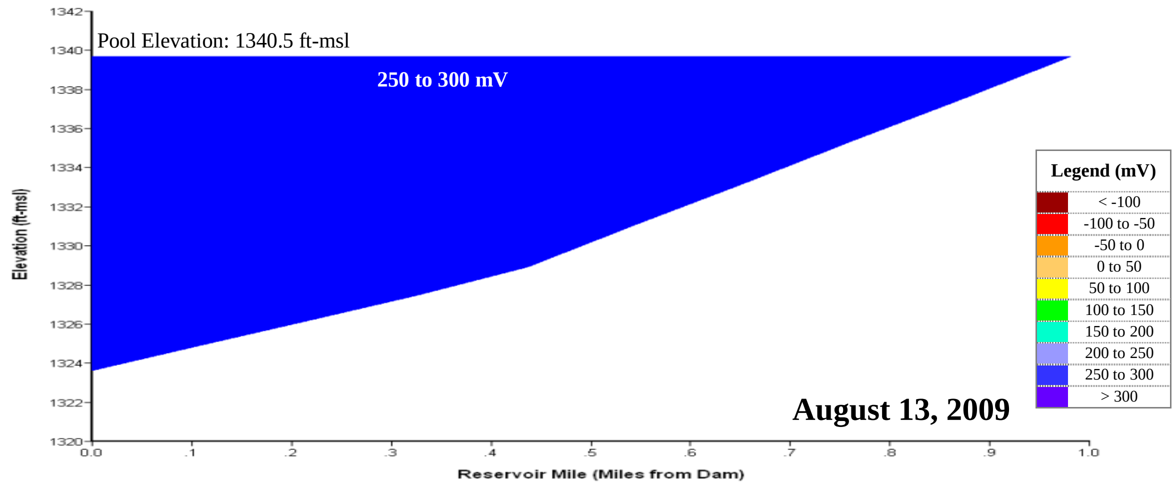


Plate 204. Longitudinal oxidation-reduction potential (mV) contour plots of East Twin Reservoir based on depth-profile ORP levels measured at sites ETNLKND1 and ETNLKML1 in 2009.



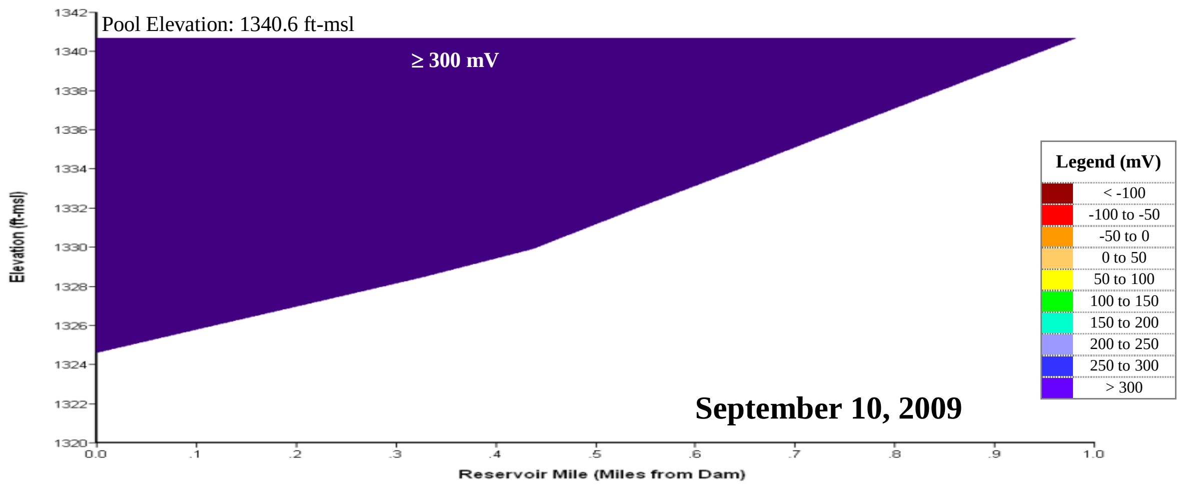


Plate 204. (Continued).

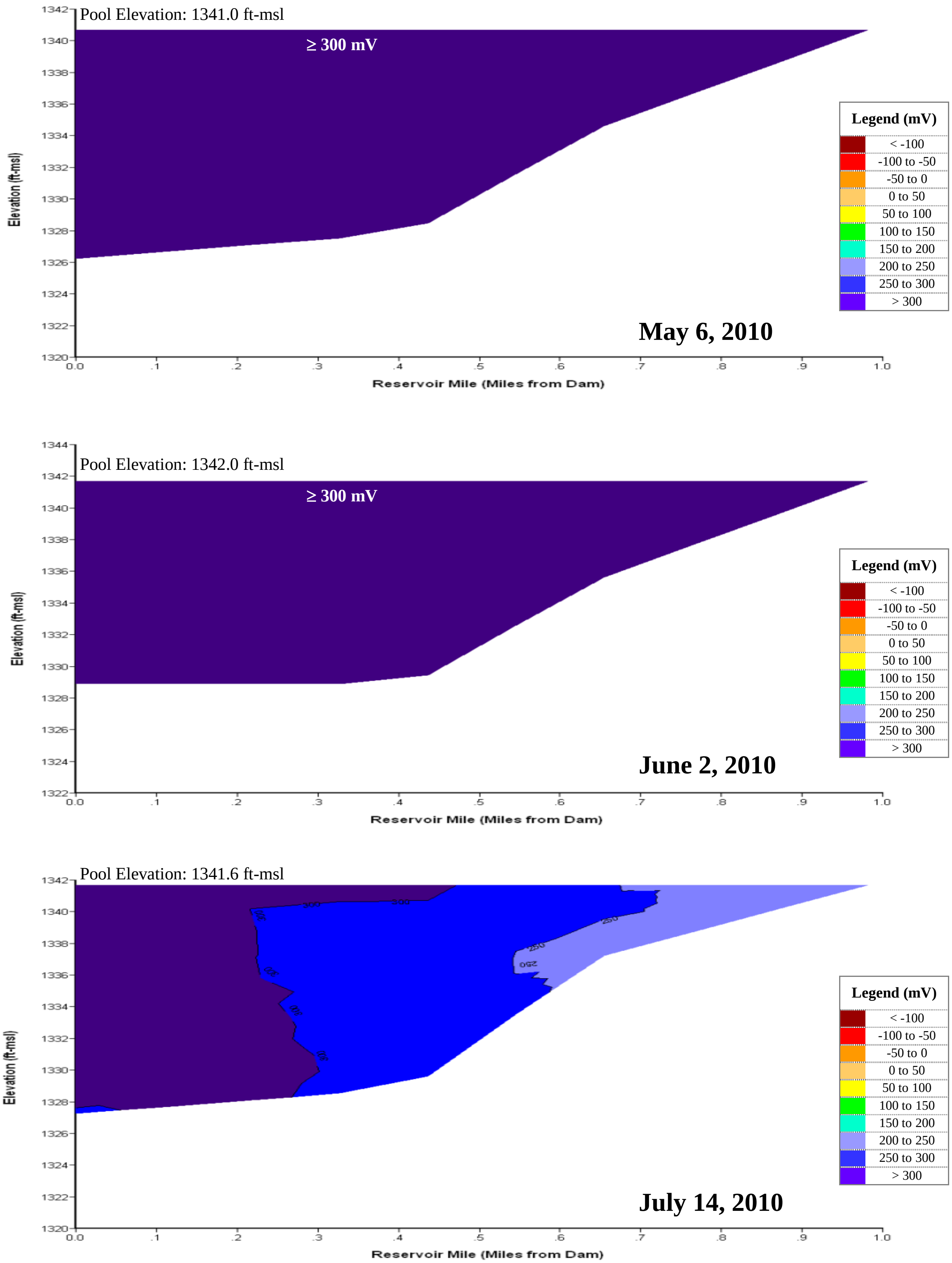
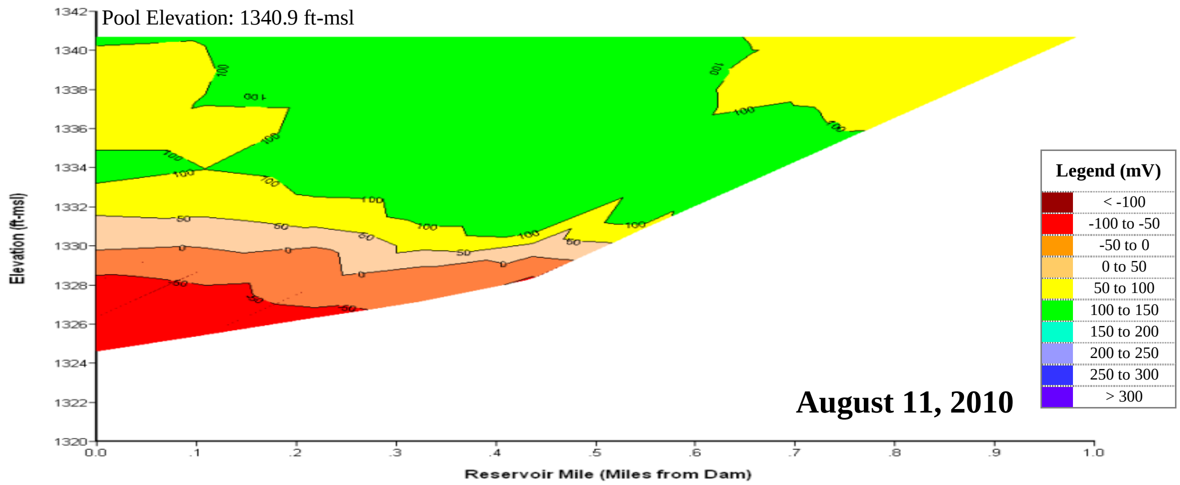


Plate 205. Longitudinal oxidation-reduction potential (mV) contour plots of East Twin Reservoir based on depth-profile ORP levels measured at sites ETNLKND1, ETNLKML1, and ETNLKUP1 in 2010.



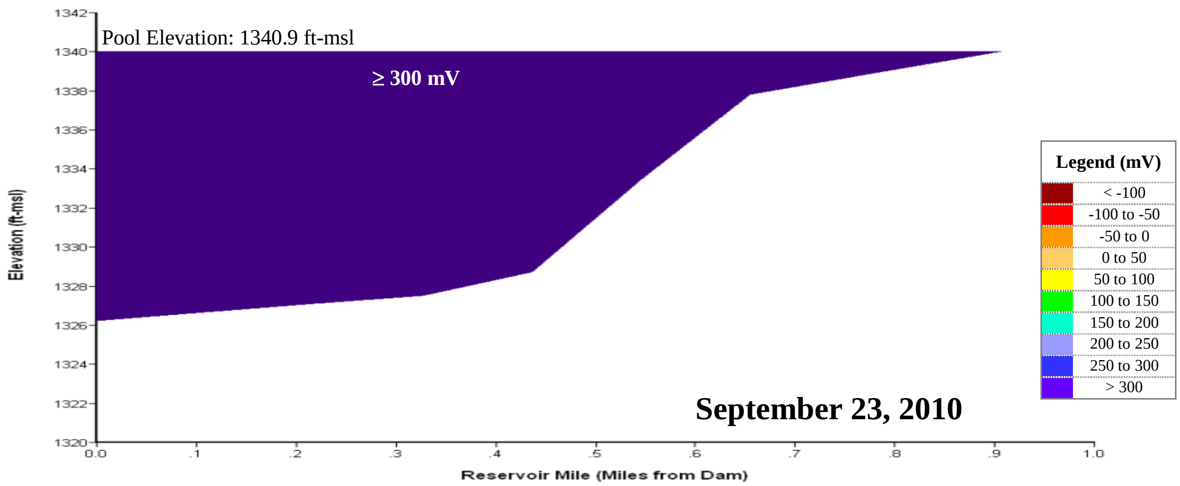


Plate 205. (Continued).

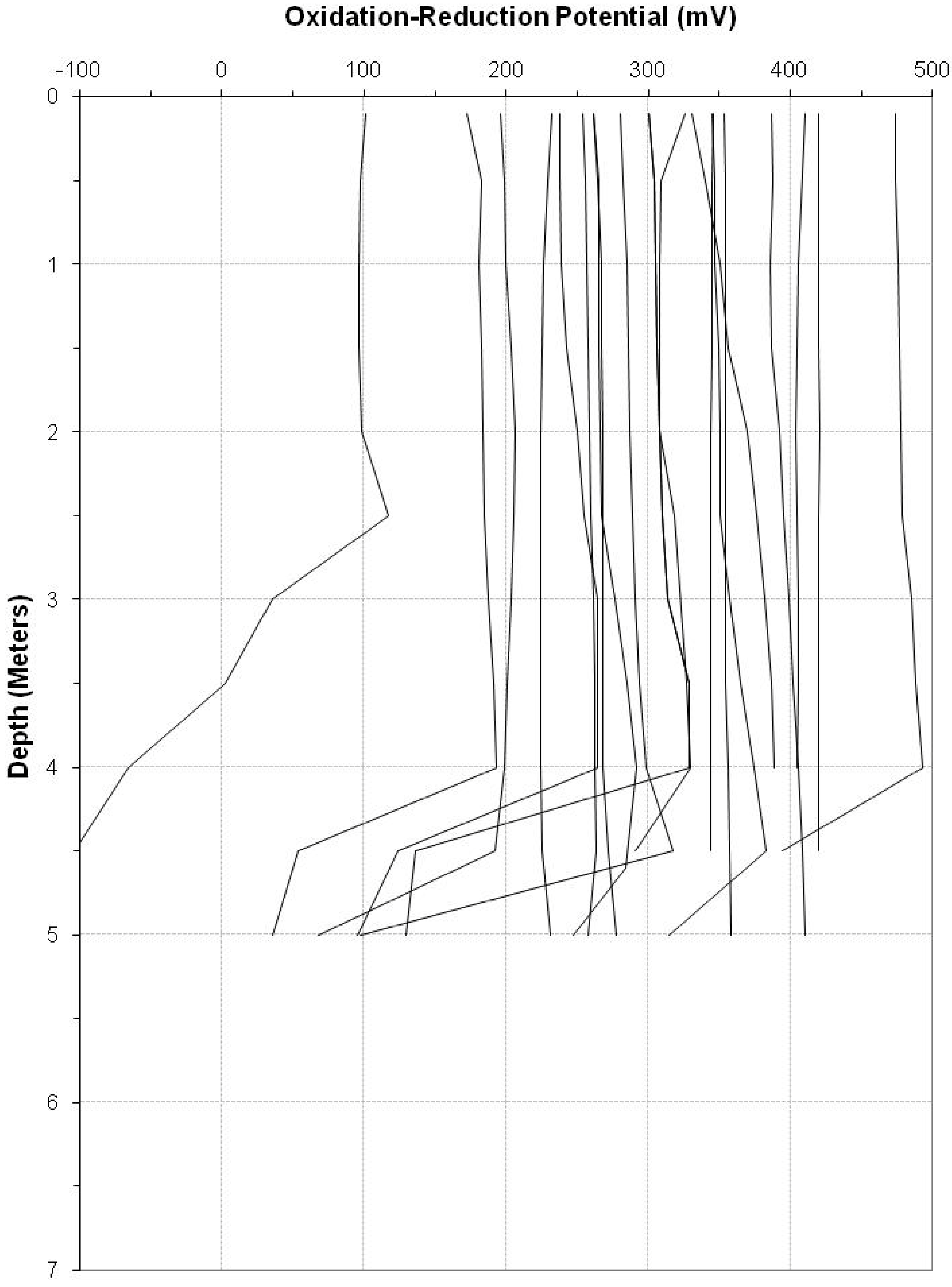
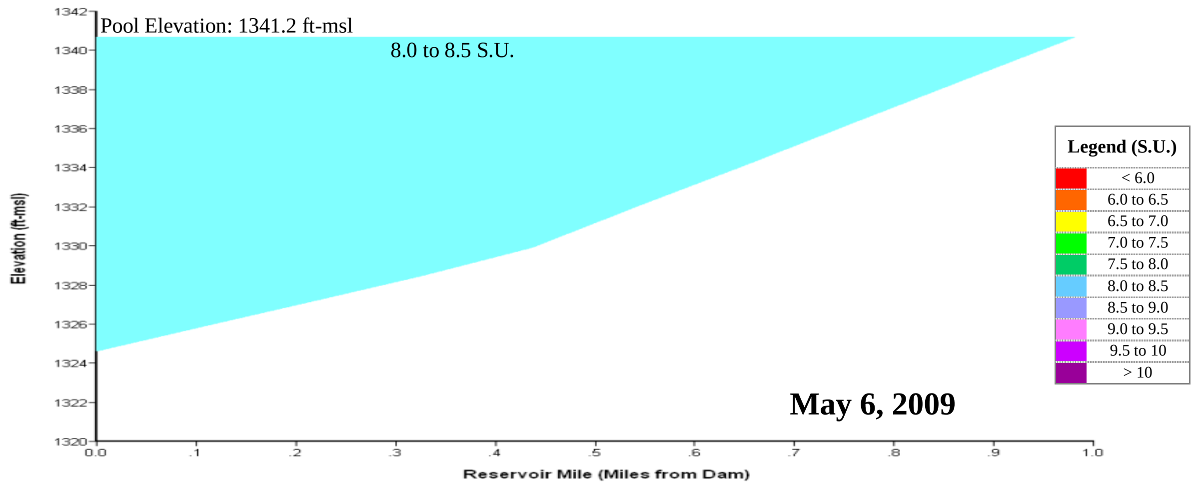
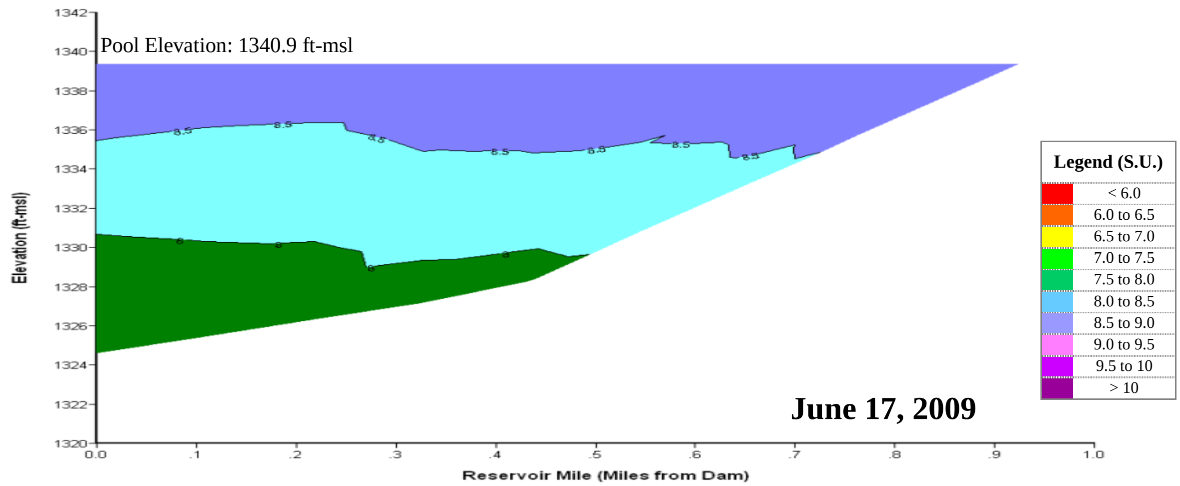


Plate 206. Oxidation-reduction potential depth profiles for East Twin Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., ETNLKND1) during the summer of the 5-year period of 2006 through 2010.





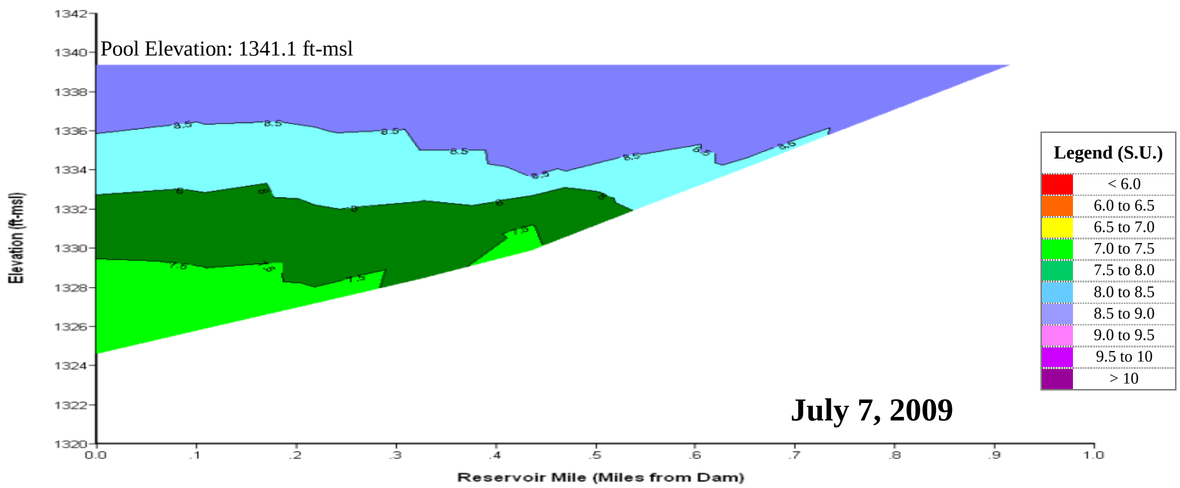
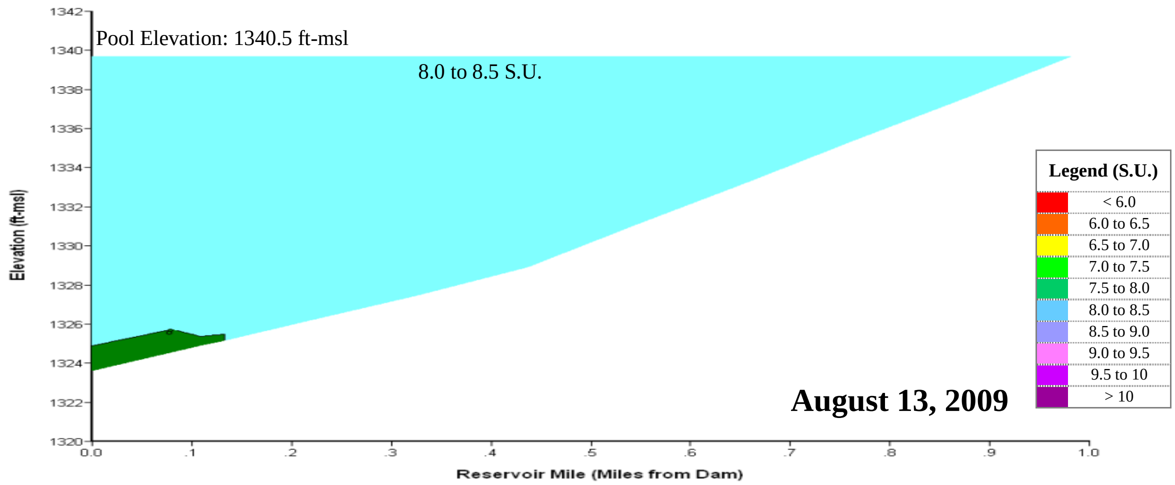


Plate 207. Longitudinal pH (S.U.) contour plots of East Twin Reservoir based on depth-profile pH levels measured at sites ETNLKND1 and ETNLKML1 in 2009.



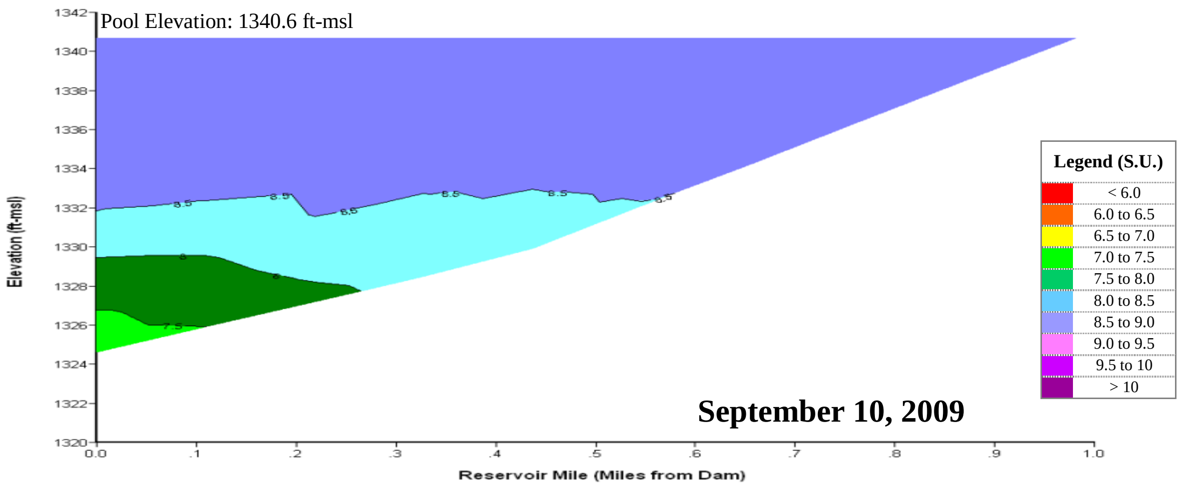


Plate 207. (Continued).

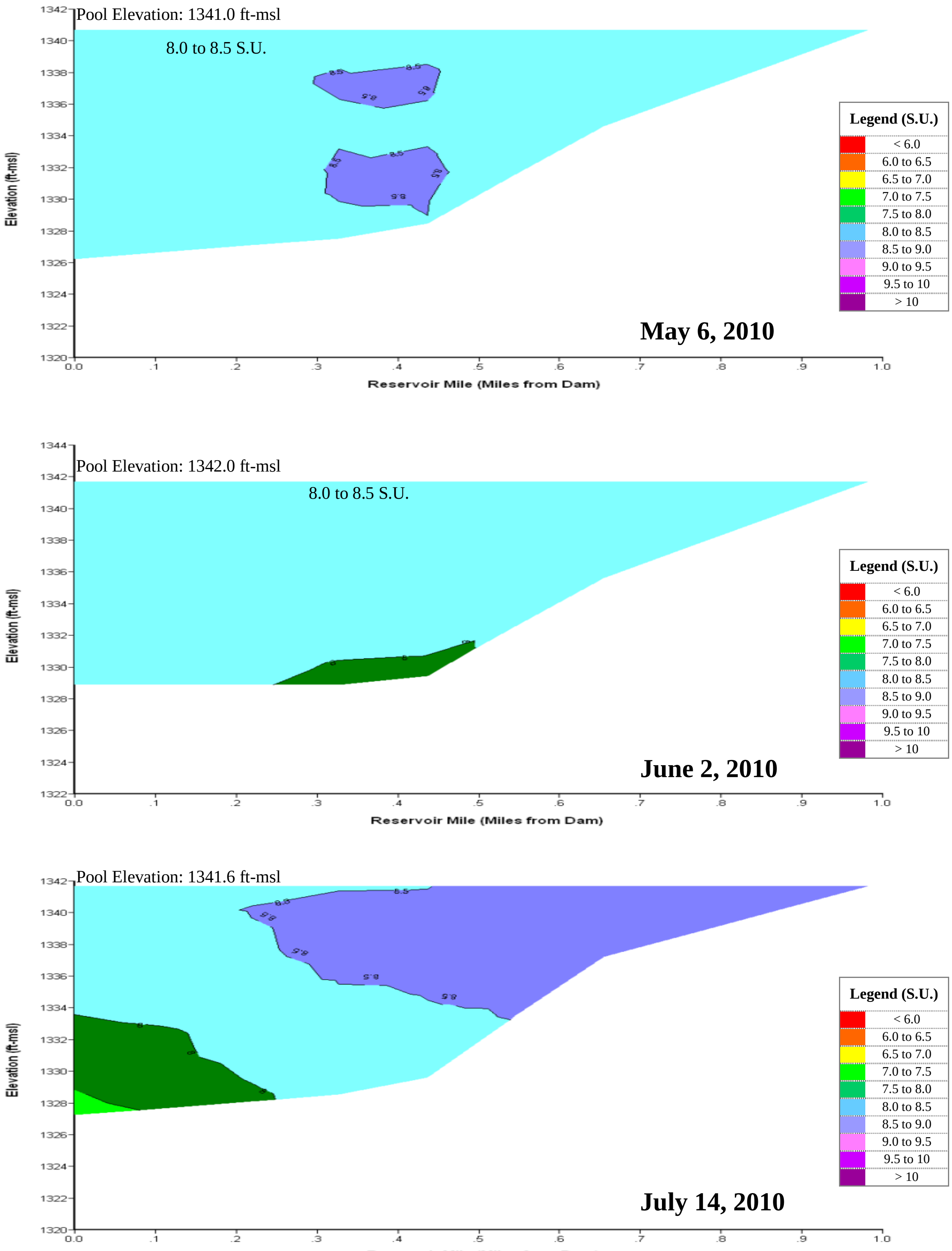
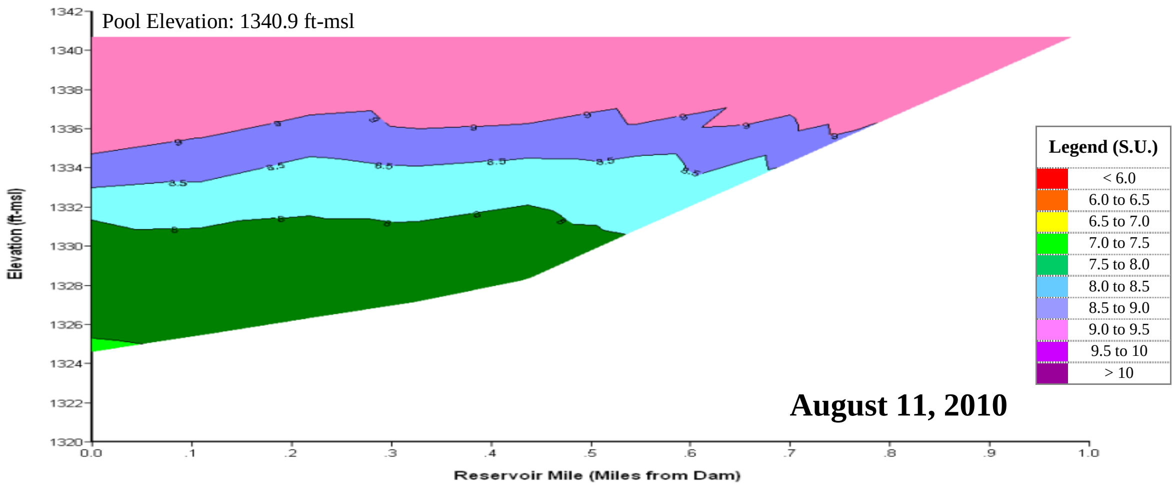


Plate 208. Longitudinal pH (S.U.) contour plots of East Twin Reservoir based on depth-profile pH levels measured at sites ETNLKND1, ETNLKML1, and ETNLKUP1 in 2010.



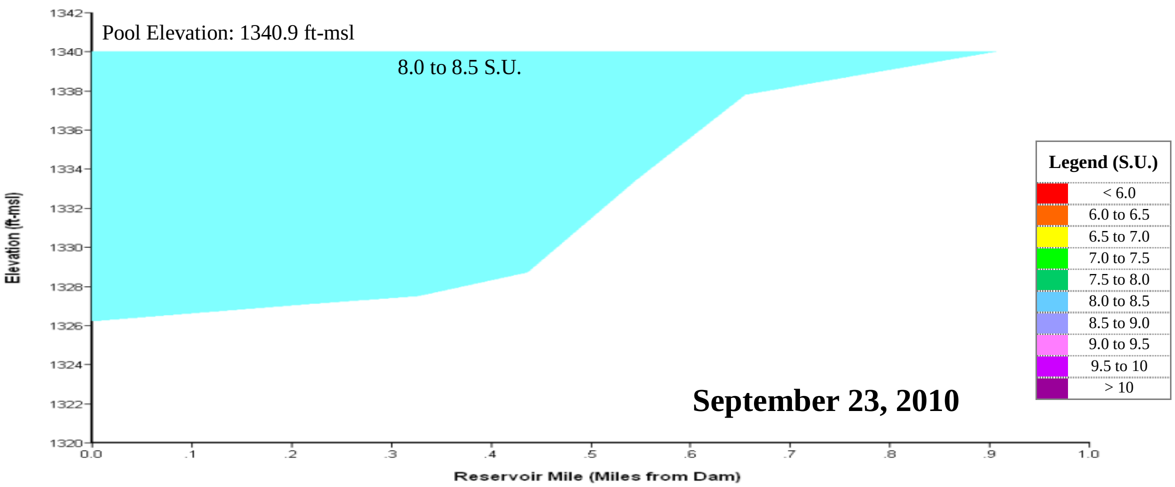


Plate 208. (Continued).

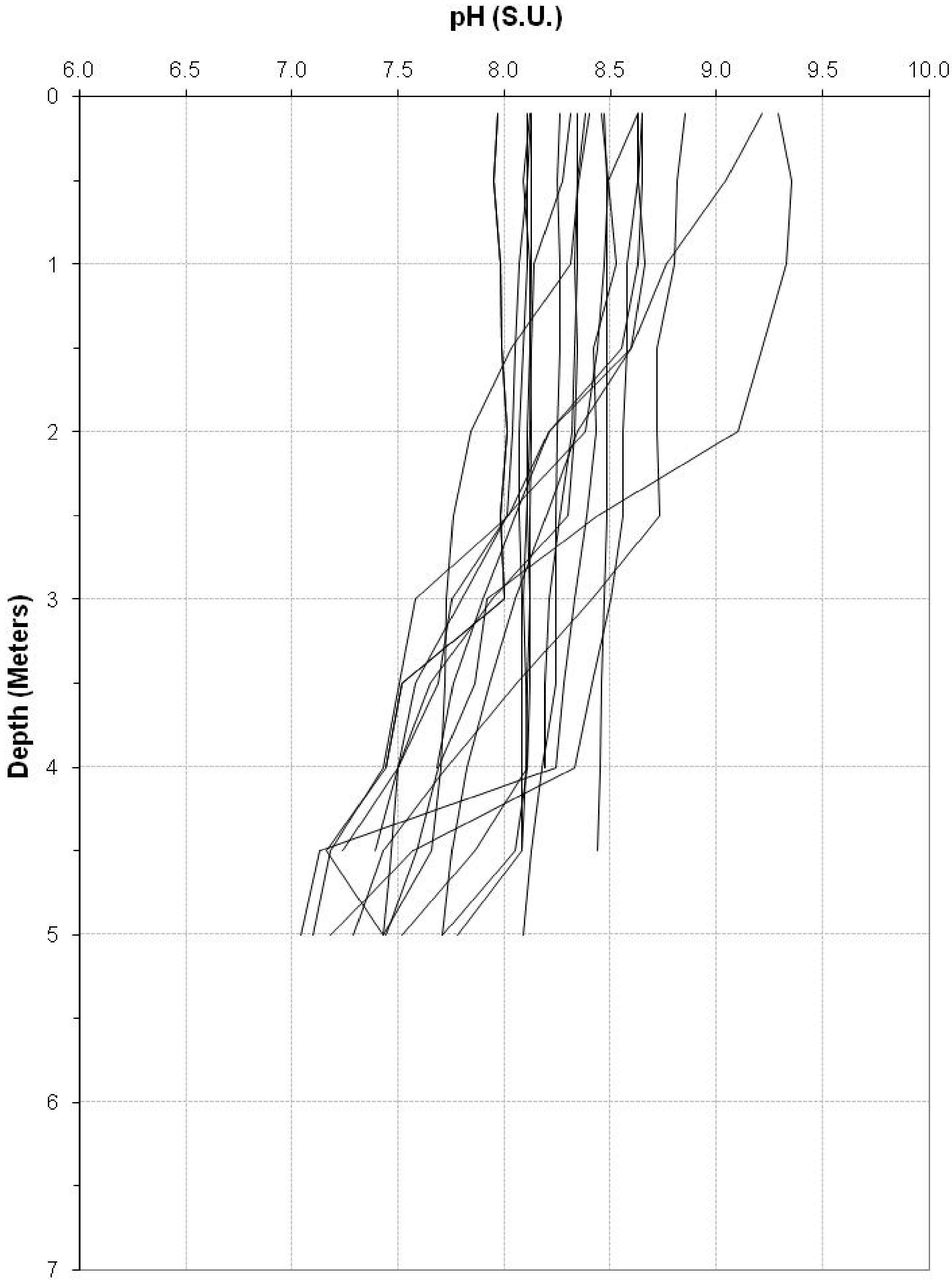


Plate 209. pH depth profiles for East Twin Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., ETNLKND1) during the summer of the 5-year period of 2006 through 2010.

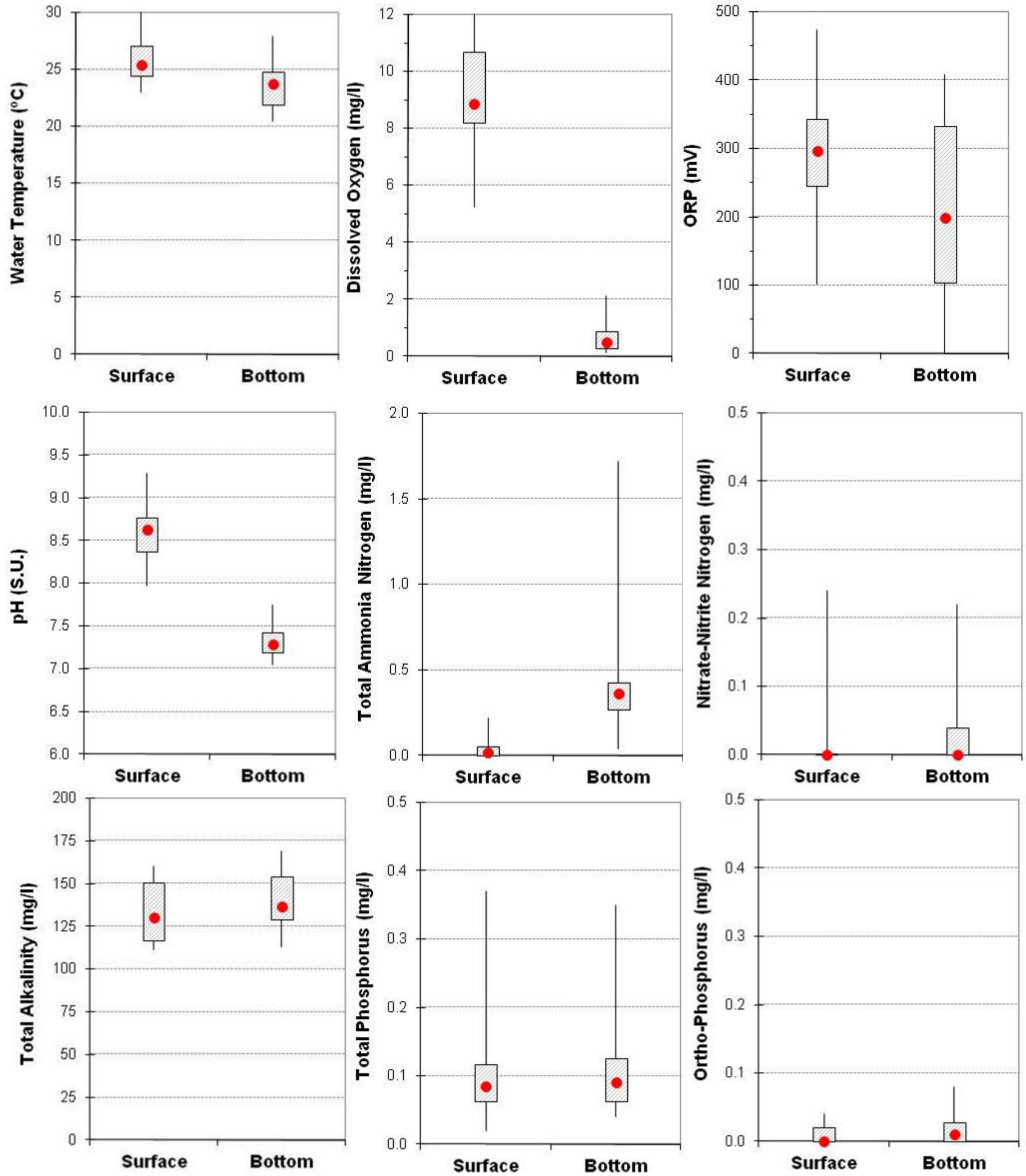
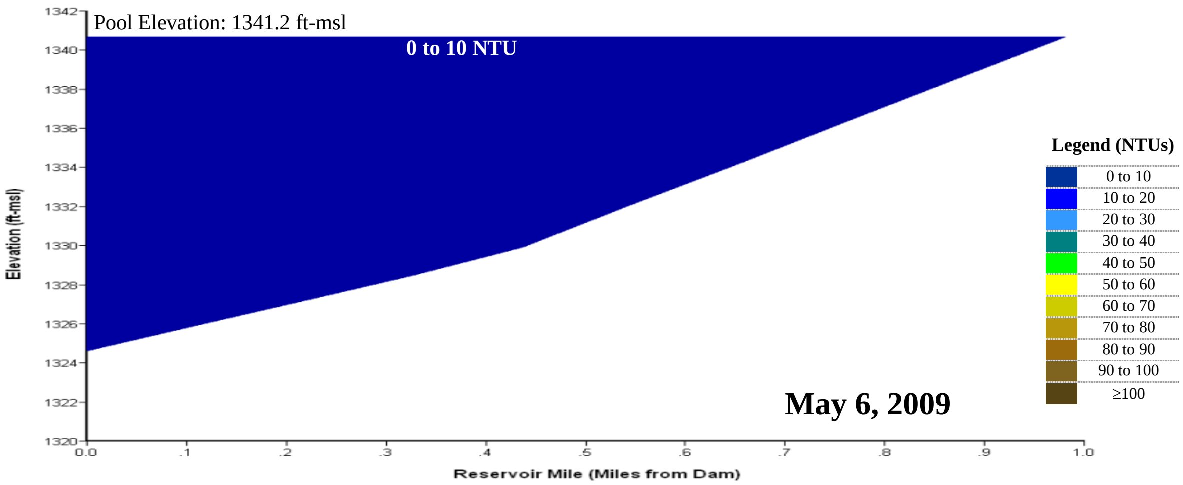
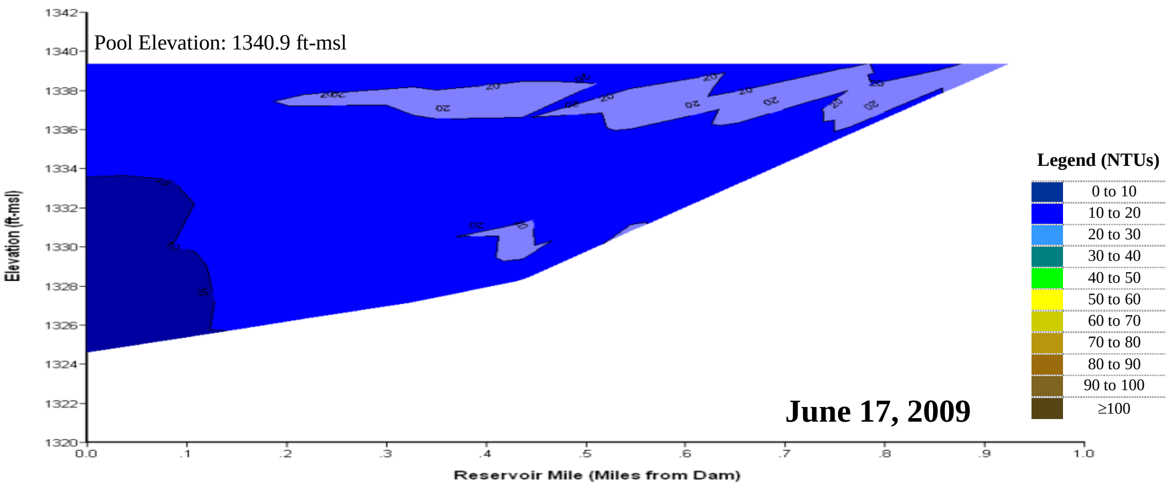


Plate 210. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, alkalinity, total ammonia nitrogen, nitrate-nitrite nitrogen, total phosphorus, and ortho-phosphorus measured in East Twin Reservoir when summer hypoxic conditions were present during the 5-year period 2006 through 2010. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)





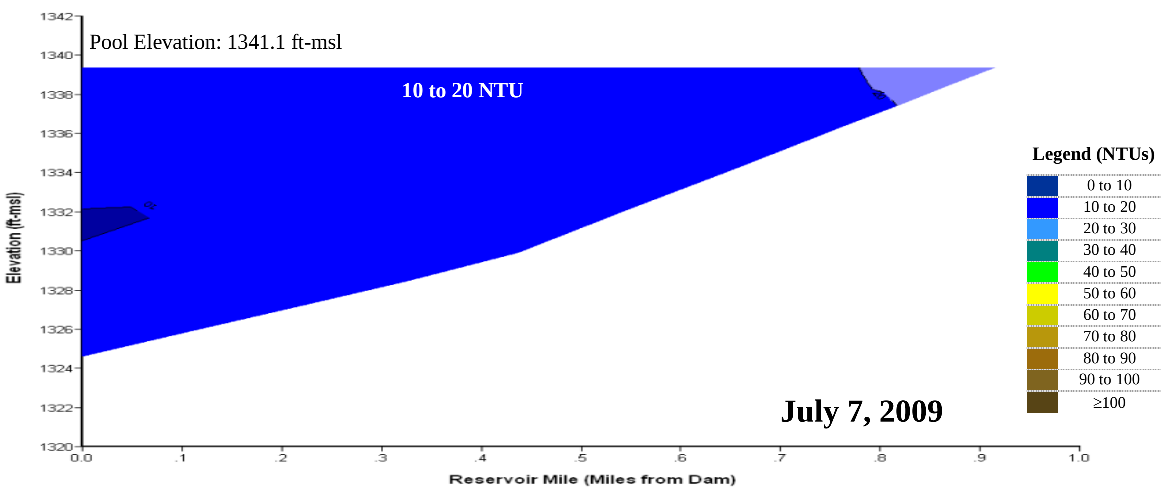
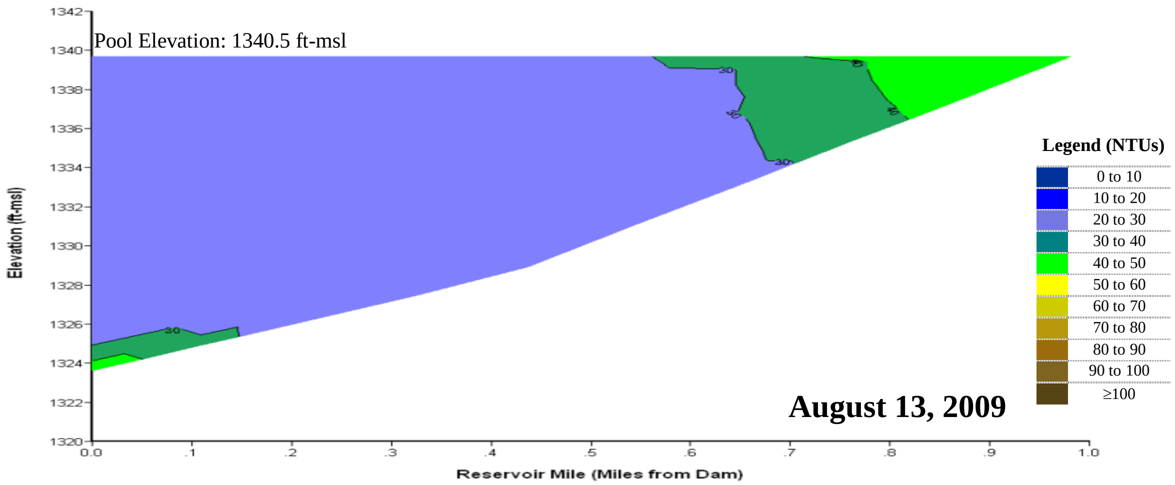


Plate 211. Longitudinal turbidity (NTU) contour plots of East Twin Reservoir based on depth-profile turbidity levels measured at sites ETNLKND1 and ETNLKML1 in 2009.



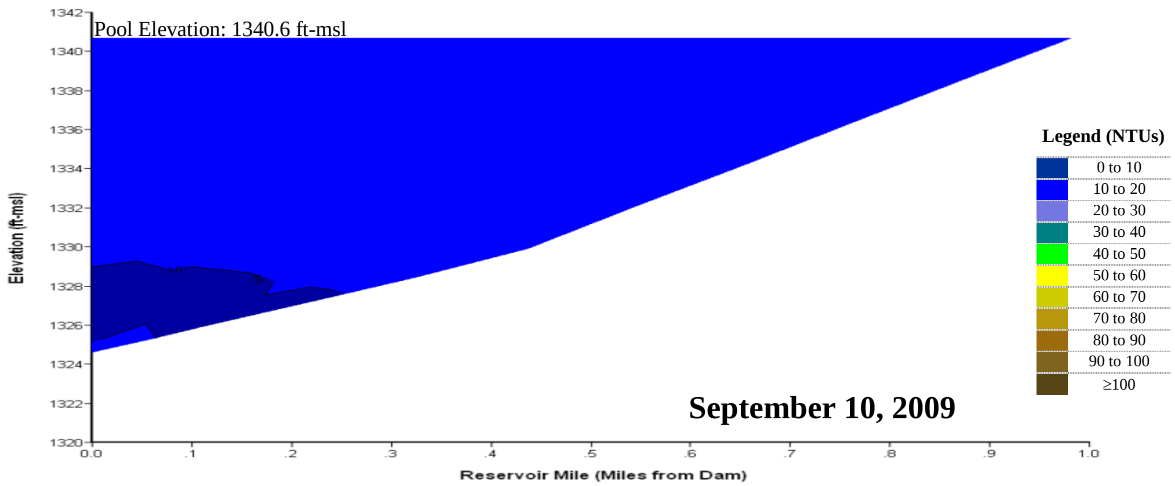


Plate 211. (Continued).

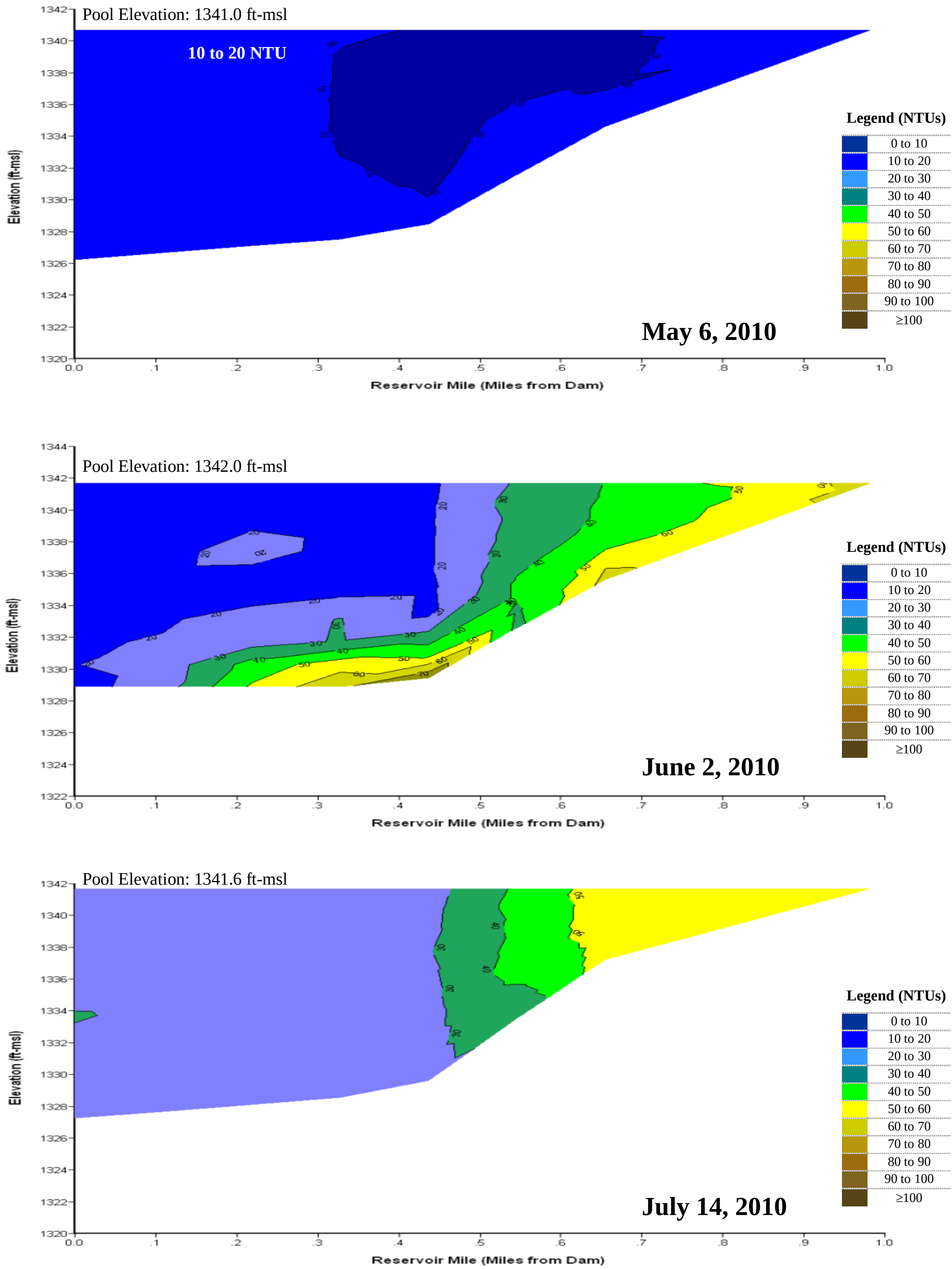
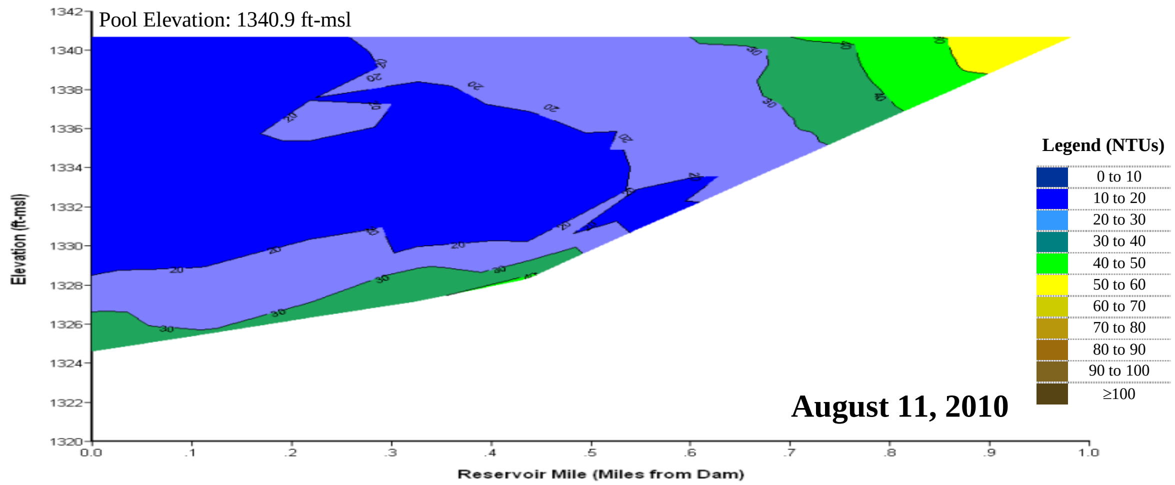


Plate 212. Longitudinal turbidity (NTU) contour plots of East Twin Reservoir based on depth-profile turbidity levels measured at sites ETNLKND1, ETNLKML1, and ETNLKUP1 in 2010.



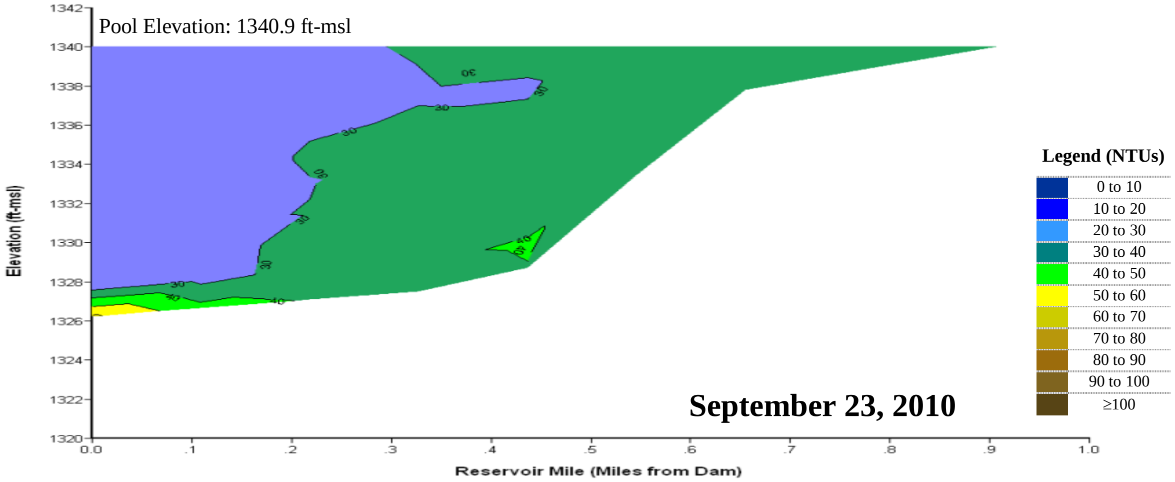


Plate 212. (Continued).

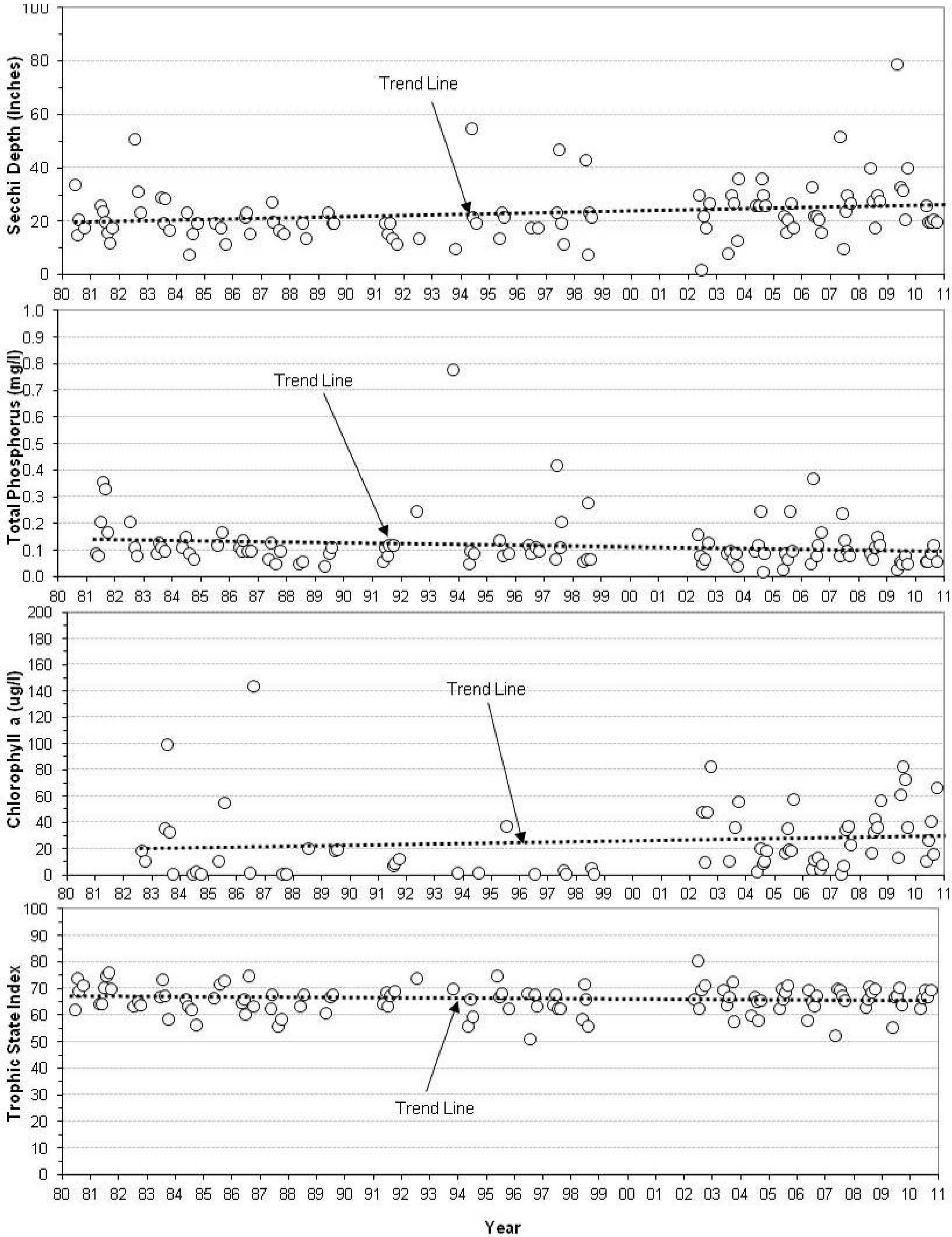


Plate 213. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in East Twin Reservoir at the near-dam, ambient site (i.e., site ETNLKND1) over the 31-year period of 1980 through 2010.

Plate 214. Summary of runoff water quality conditions monitored in the main tributary inflow to East Twin Reservoir at monitoring site ETNNF1 during the 5-year period 2004 through 2008**.** Runoff conditions have not been monitored since 2008.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Kjeldahl N, Total (mg/l)	0.1	6	4.8	4.0	1.5	10.7	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	6	2.53	2.36	0.25	4.91	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	6	1.52	1.37	0.44	3.60	-----	-----	-----
Suspended Solids, Total (mg/l)	4	6	942	409	89	3,880	-----	-----	-----
Acetochlor, Total (ug/l)(C)	0.05	2	9.0	9.0	0.99	17.01	-----	-----	-----
Alachlor, Total (ug/l)(C)	0.05	2	15.03	15.03	0.13	29.92	760(1), 76(2)	0	0%
Atrazine, Total (ug/l)(C)	0.05	4	9.21	9.44	0.91	17.04	330(1), 12(2)	2	50%
Metolachlor, Total (ug/l)(C)	0.05	4	4.97	4.07	0.25	11.50	390(1), 100(2)	0	0%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Acute criterion for aquatic life.
(2) Chronic criterion for aquatic life.
(C) Immunoassay analysis.

Plate 215. Summary of water quality conditions monitored in Wagon Train Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site WAGLKND1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	25	1287.5	1287.9	1284.0	1290.5	-----	-----	-----
Water Temperature (°C)	0.1	225	23.1	23.9	15.0	30.0	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	225	5.9	6.1	0.2	13.3	≥ 5(2)	79	35%
Dissolved Oxygen (% Sat.)	0.1	218	70.8	73.5	2.4	165.9	-----	-----	-----
Specific Conductance (umho/cm)	1	218	368	352	267	471	2,000(3)	0	0%
pH (S.U.)	0.1	218	8.2	8.2	7.2	8.9	≥6.5 & ≤9.0(1)	0	0%
Turbidity (NTUs)	1	218	30	17	2	201	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	218	329	342	-88	498	-----	-----	-----
Secchi Depth (in.)	1	25	20	18	5	40	-----	-----	-----
Alkalinity, Total (mg/l)	7	50	160	154	107	209	20(1)	0	0%
Ammonia, Total (mg/l)	0.02	50	0.15	0.13	n.d.	0.90	5.72(4,5), .98(4,6)	0, 2	0%, 4%
Chlorophyll *a* (ug/l) – Field Probe	1	186	42.08	28.97	2.48	324.00	10(7)	168	90%
Chlorophyll *a* (ug/l) – Lab Determined	1	25	45.27	33.00	3.00	324.00	10(7)	19	76%
Hardness, Total (mg/l)	0.4	5	124.8	124.0	111.0	145.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	50	1.4	1.4	0.9	2.2	-----	-----	-----
Nitrogen, Total (mg/)	0.1	30	1.6	1.5	0.9	2.9	1 (7)	47	94%
Nitrate-Nitrite N, Total (mg/l)	0.02	50	-----	n.d.	n.d.	1.30	100(3)	-----	-----
Phosphorus, Total (mg/l)	0.10	50	0.3	0.3	0.1	0.7	0.05(7)	50	100%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	0.16	0.15	n.d.	0.41	-----	-----	-----
Suspended Solids, Total (mg/l)	4	50	15	12	n.d.	90	-----	-----	-----
Aluminum, Dissolved (ug/l)	25	5	-----	n.d.	n.d.	337	750(5), 87(6)	0, 1	0%, 20%
Antimony, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	1	88(5), 30(6)	0	0%
Arsenic, Dissolved (ug/l)	3	5	15	13	12	22	340(5), 16.7(8)	0, 1	0%, 20%
Beryllium, Dissolved (ug/l)	3	5	-----	n.d.	n.d.	n.d.	130(5), 5.3(6)	0	0%
Cadmium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	7.3(5), 0.3(6)	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	706(5), 92(6)	0	0%
Copper, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	16(5), 11(6)	0	0%
Lead, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	82(5), 3 (6)	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4(5)	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77(6)	0	0%
Nickel, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	562(5), 62(6)	0	0%
Selenium, Total (ug/l)	2	5	-----	n.d.	n.d.	14	20(3,5), 5(6)	0, 1	0, 20%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	5(5)	0	0%
Thallium (ug/l)	3	5	-----	n.d.	n.d.	n.d.	1,400(5), 6.3(8)	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	141(5,6)	0	0%
Microcystin, Total (ug/l)	0.05	25	-----	n.d.	n.d.	0.21	20(9)	0	0%
Acetochlor, Total (ug/l)(C)	0.05	15	-----	0.50	n.d.	1.70	-----	-----	-----
Alachlor, Total (ug/l)(C)	0.05	10	-----	0.14	n.d.	0.29	760(5), 76(6)	0	0%
Atrazine, Total (ug/l)(C)	0.05	25	1.76	1.50	n.d.	8.70	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l)(C)	0.05	25	0.80	0.40	n.d.	2.50	390(5), 100(6)	0	0%
Pesticide Scan (ug/l)(D)	0.05						-----	-----	-----
Acetochlor		5	-----	n.d.	n.d.	1.80	-----	-----	-----
Atrazine		5	4.54	1.80	0.50	10.00	330(5), 12(6)	0	0%
Deethylatrazine		4	-----	0.35	n.d.	1.00	-----	-----	-----
Dimethenamid		4	-----	n.d.	n.d.	0.60	-----	-----	-----
Metolachlor		5	-----	n.d.	n.d.	1.70	390(5), 100(6)	0	0%

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l microcystins in recreation water for impairment assessment.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 216. Summary of water quality conditions monitored in Wagon Train Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site WAGLKML1) from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, and ORP are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	15	1286.9	1287.6	1284.0	1289.7	-----	-----	-----
Water Temperature (°C)	0.1	116	23.2	24.9	3.2	28.3	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	187	6.7	7.0	0.4	11.3	≥ 5[2]	37	20%
Dissolved Oxygen (% Sat.)	0.1	181	80.5	82.8	4.4	144.0	-----	-----	-----
Specific Conductance (umho/cm)	1	181	367	350	272	466	2,000[3]	0	0%
pH (S.U.)	0.1	181	8.3	8.3	7.4	9.3	≥6.5 & ≤9.0[1]	6	3%
Turbidity (NTUs)	1	181	33	20	2	251	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	181	342	353	-36	504	-----	-----	-----
Secchi Depth (in.)	1	25	18	18	6	40	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	148	51	28	2	447	10[4]	131	89%

n.d. = Not detected.

[A] Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

[B] [1] General criteria for aquatic life.
[2] Use-specific criteria for aquatic life.
[3] Agricultural criteria for surface waters.
[4] Nutrient criteria for aquatic life.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

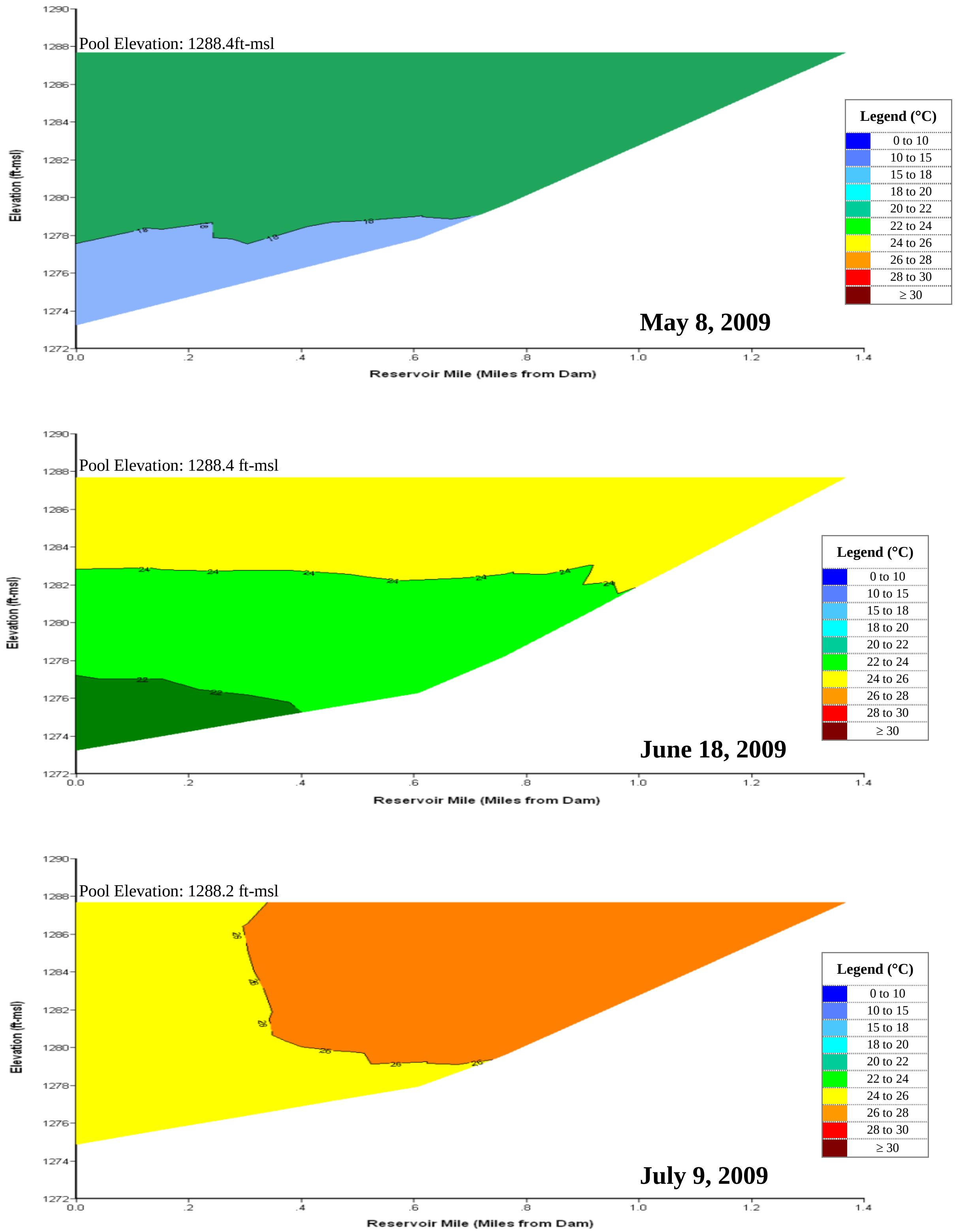
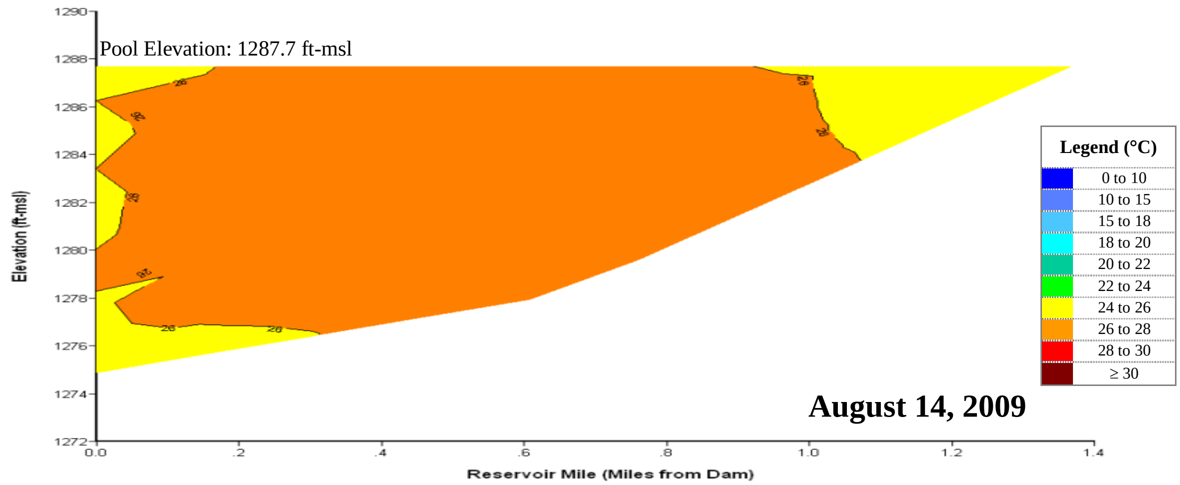


Plate 217. Longitudinal water temperature (°C) contour plots of Wagon Train Reservoir based on depth-profile water temperatures measured at sites WAGLKND1 and WAGLKML1 in 2009.



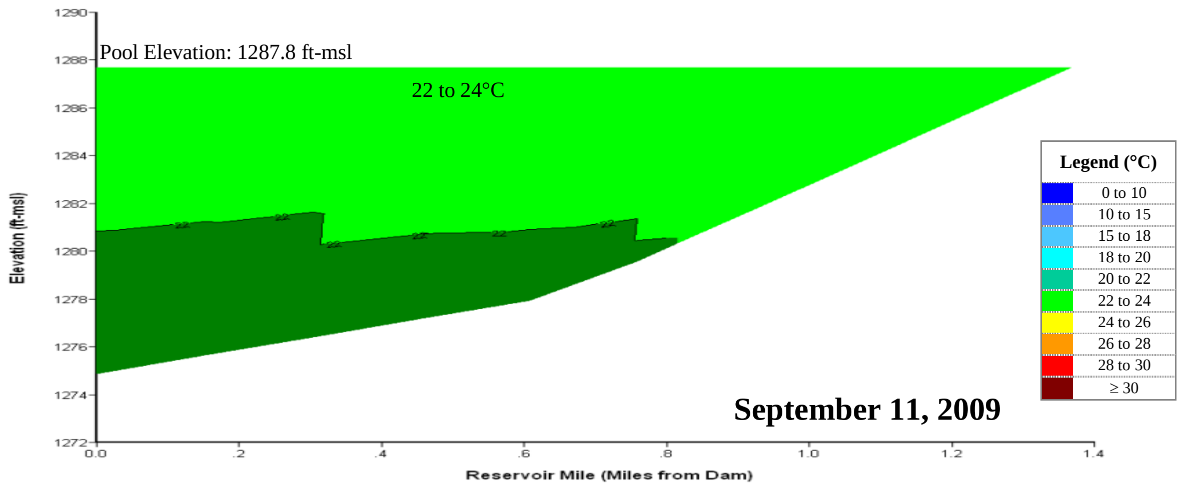


Plate 217. (Continued).

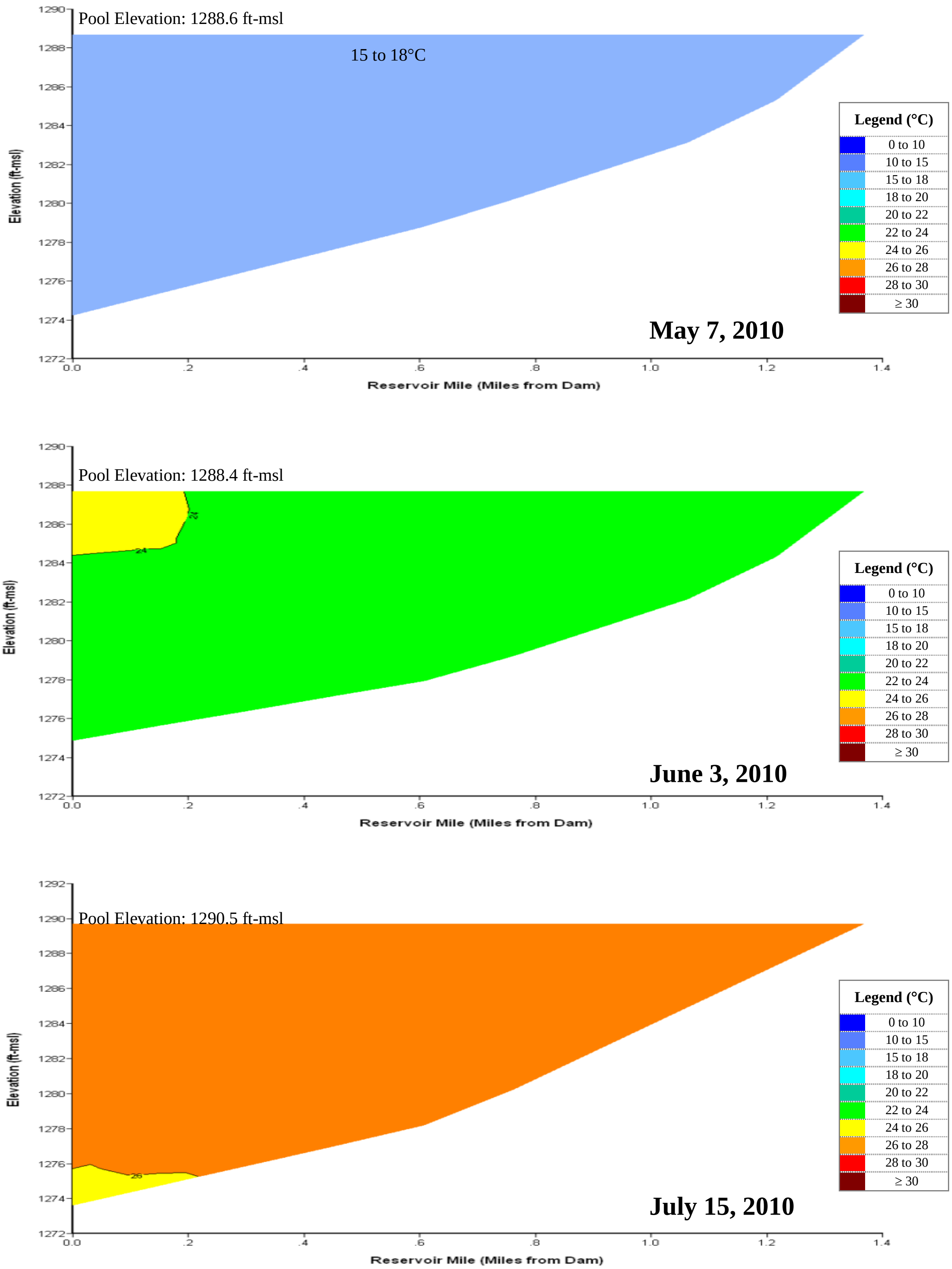
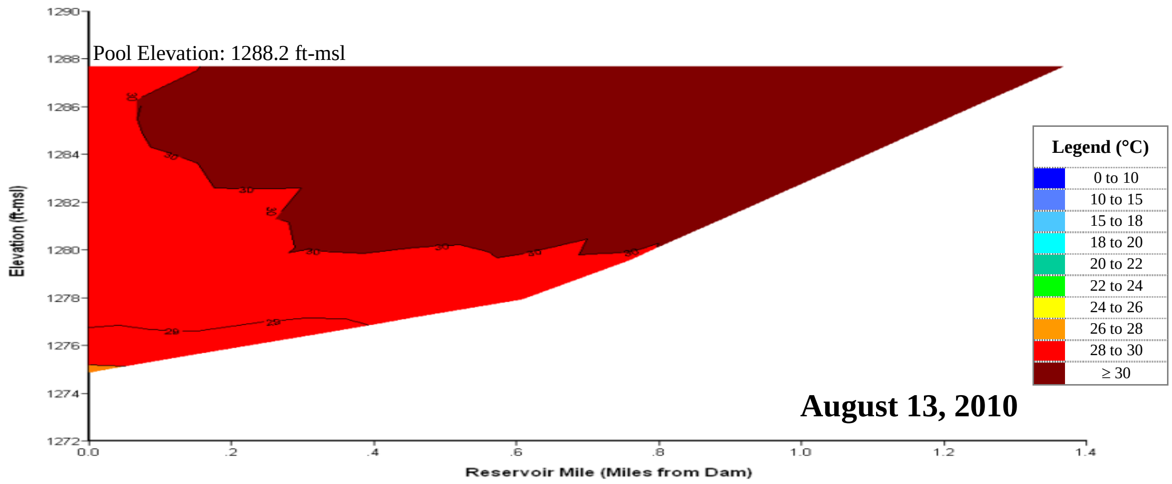


Plate 218. Longitudinal water temperature (°C) contour plots of Wagon Train Reservoir based on depth-profile water temperatures measured at sites WAGLKND1, WAGLKML1, and WAGLKUP1 in 2010.



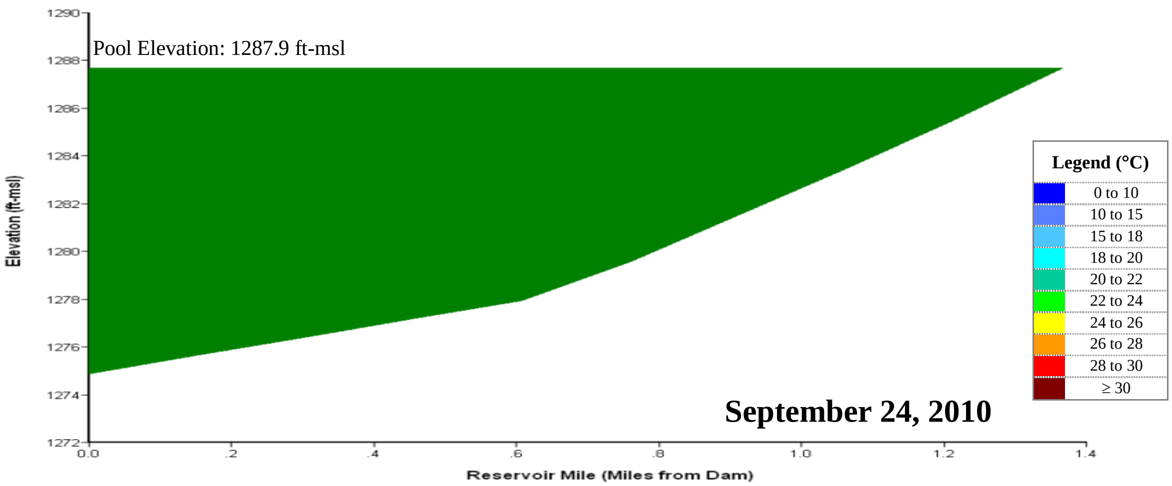


Plate 218. (Continued).

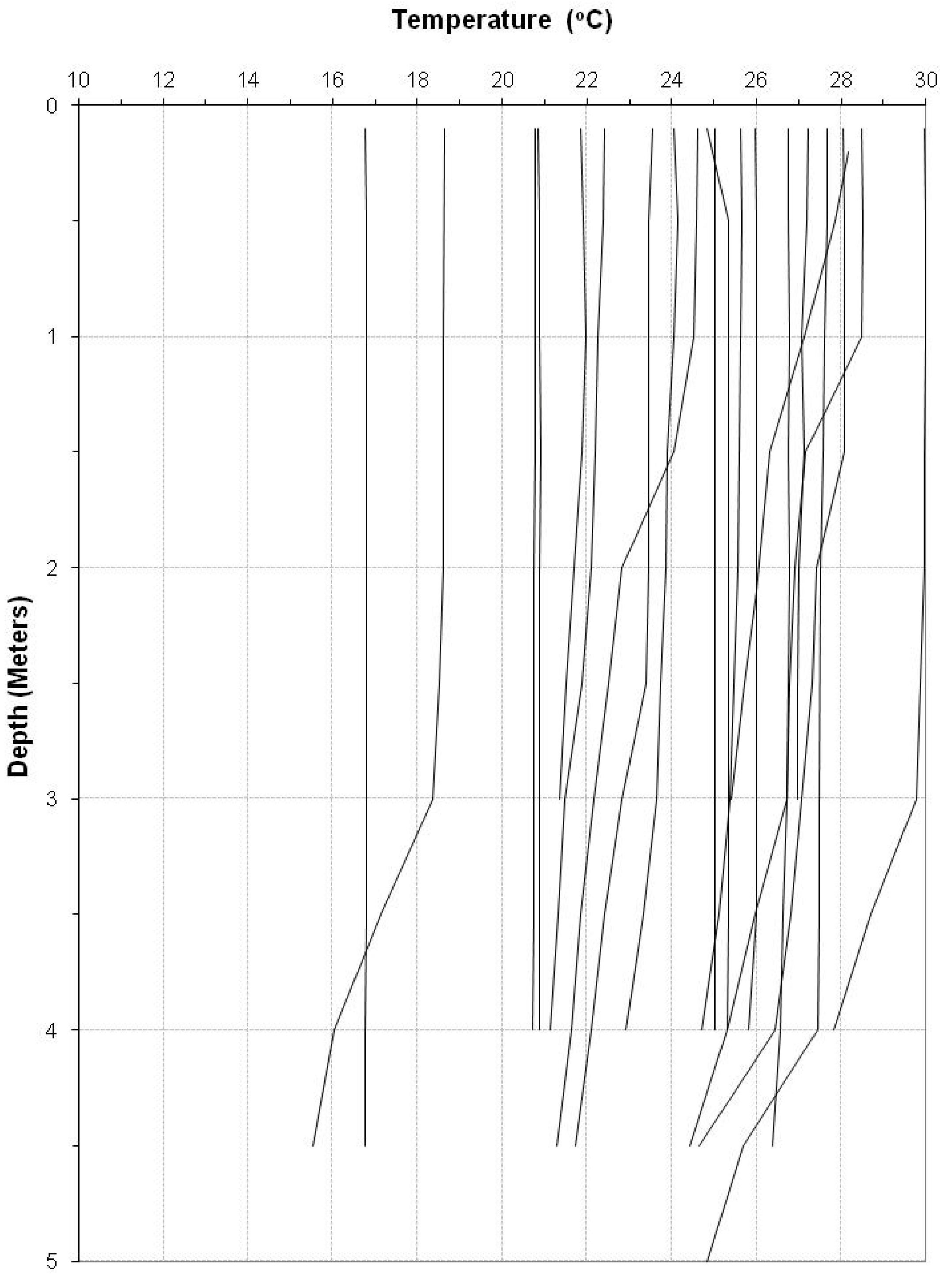


Plate 219. Temperature depth profiles for Wagon Train Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., WAGLKND1) during the summer over the 5-year period of 2006 through 2010.

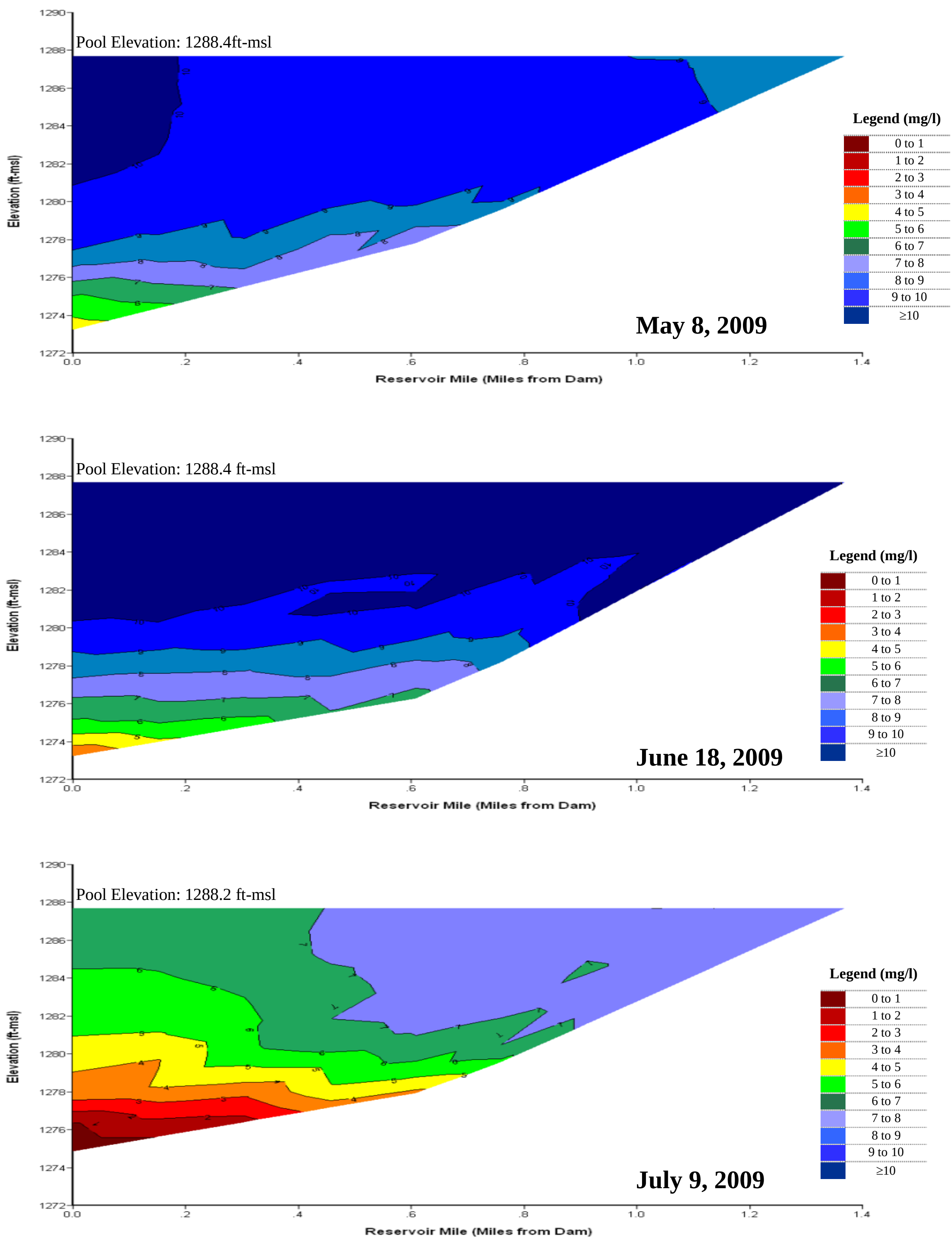
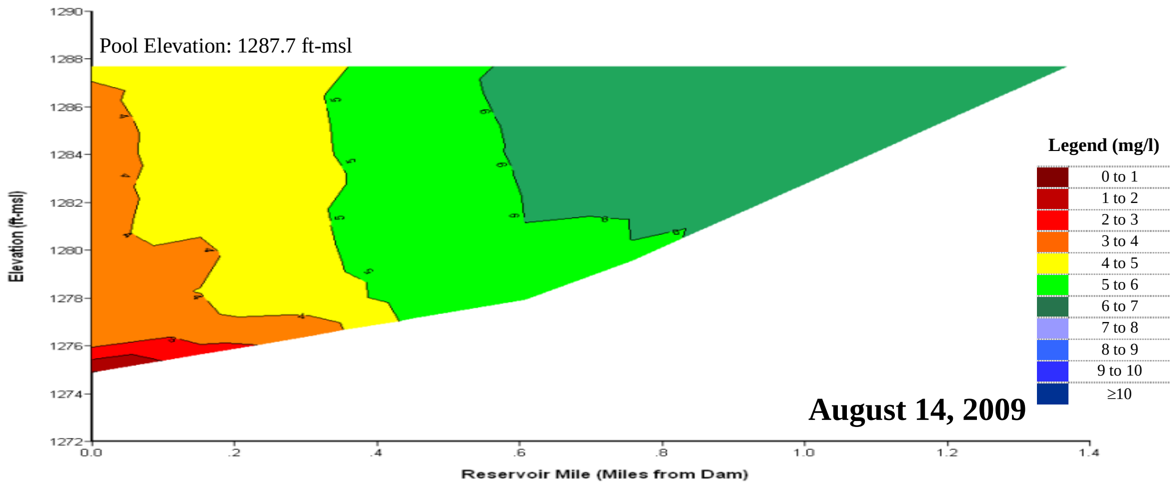


Plate 220. Longitudinal dissolved oxygen (mg/l) contour plots of Wagon Train Reservoir based on depth-profile dissolved oxygen concentrations measured at sites WAGLKND1 and WAGLKML1 in 2009.



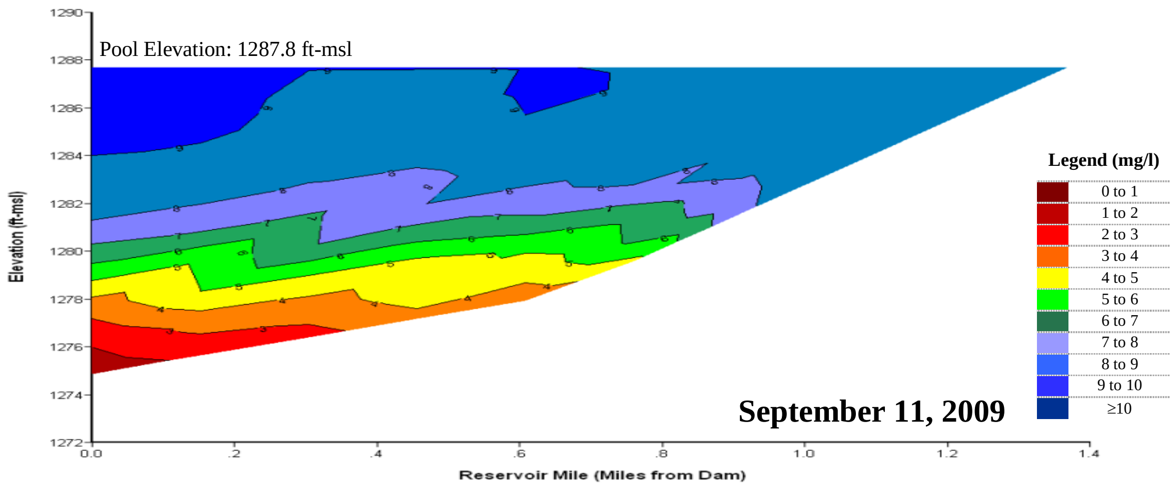


Plate 220. (Continued).

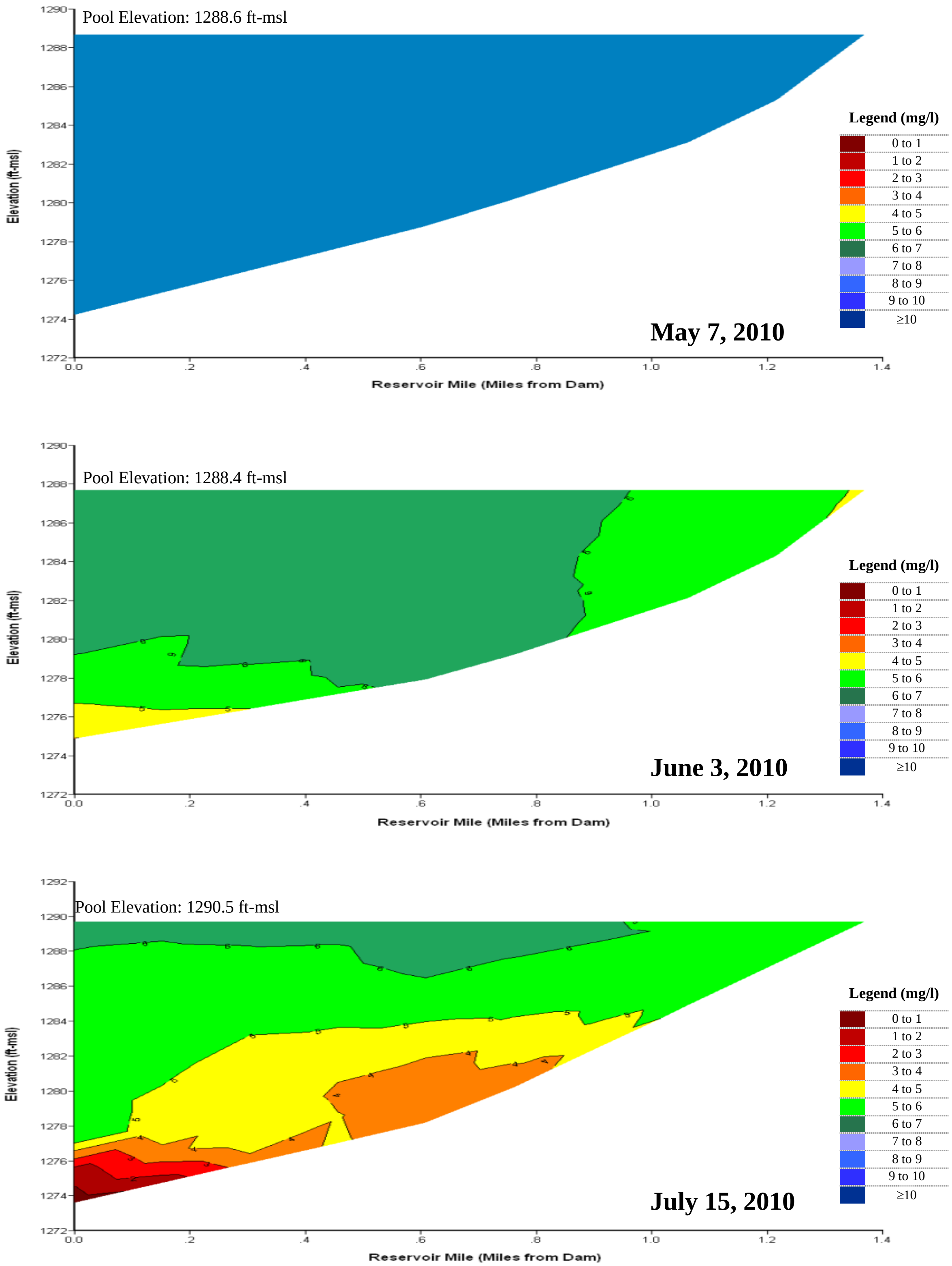
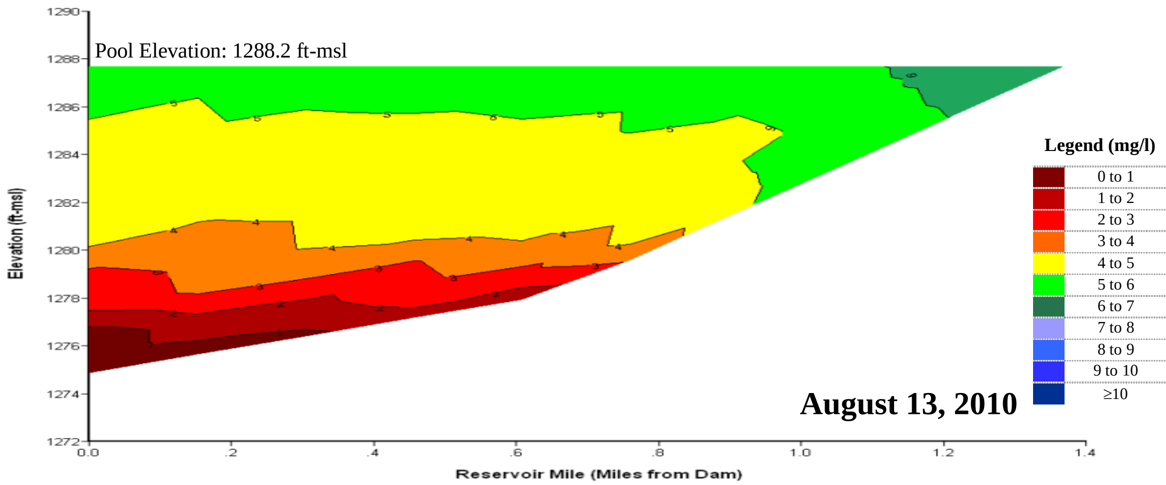


Plate 221. Longitudinal dissolved oxygen (mg/l) contour plots of Wagon Train Reservoir based on depth-profile dissolved oxygen concentrations measured at sites WAGLKND1, WAGLKML1, and WAGLKUP1 in 2010.



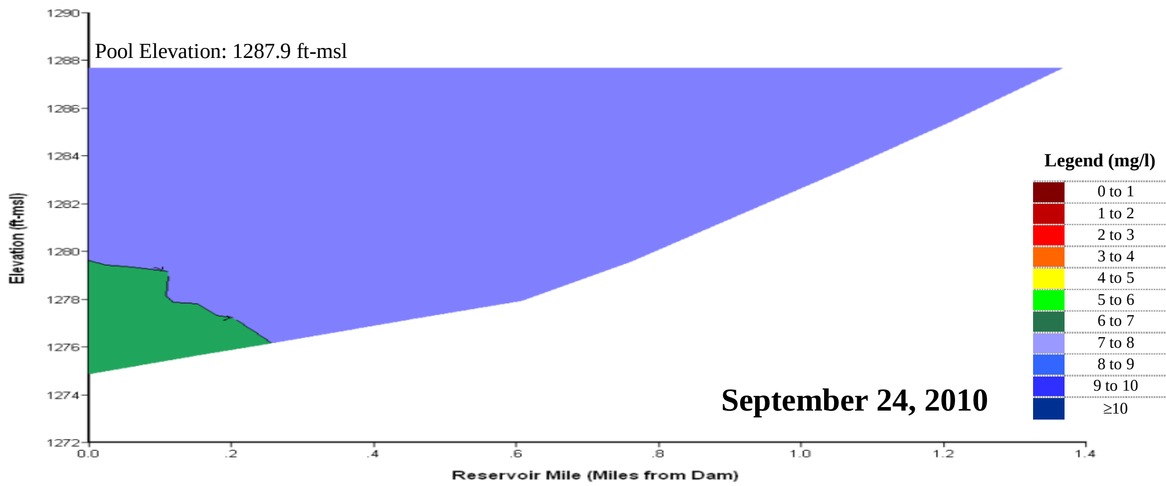


Plate 221. (Continued).

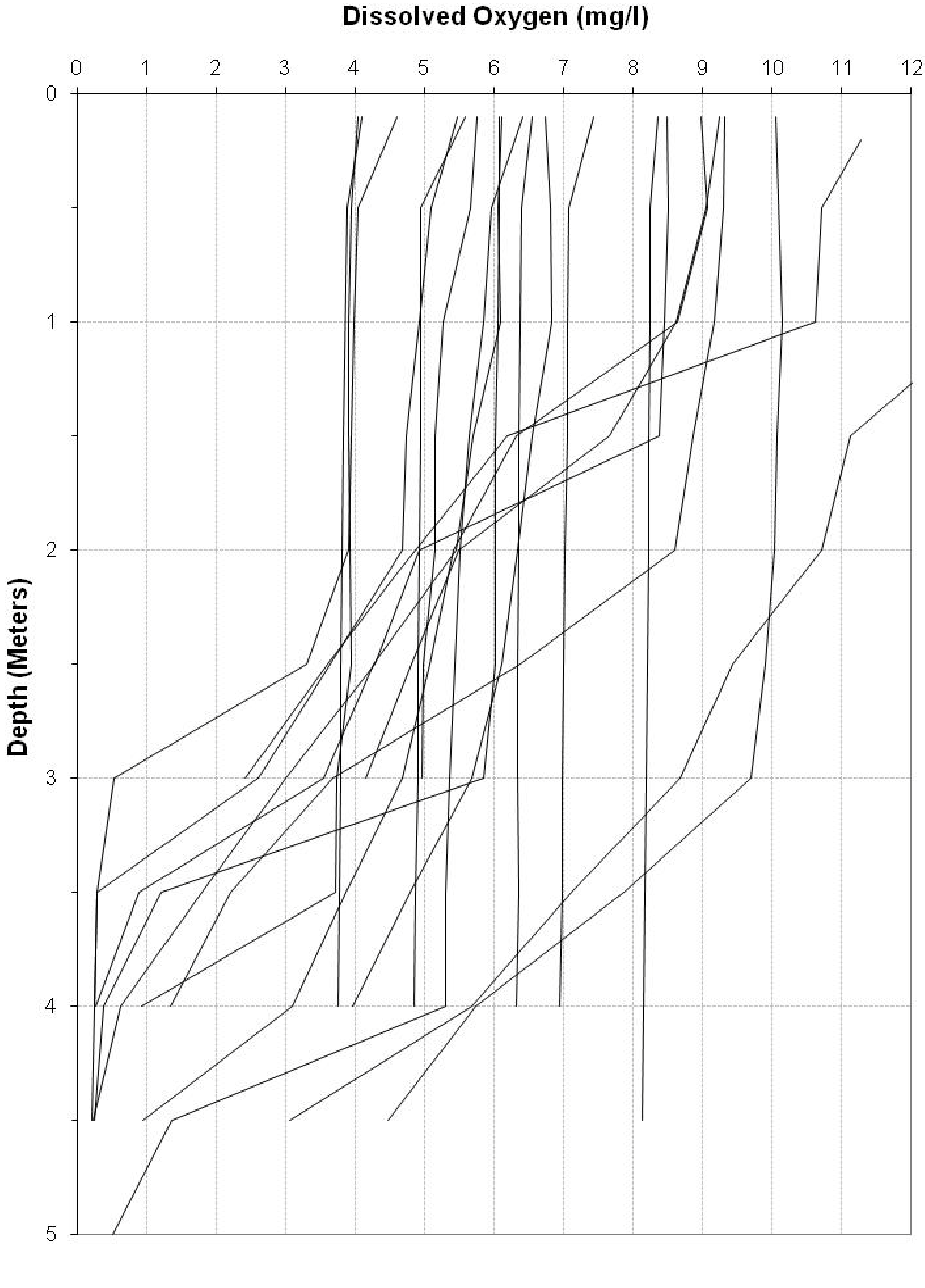


Plate 222. Dissolved oxygen depth profiles for Wagon Train Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., WAGLKND1) during the summer over the 5-year period of 2006 through 2010.

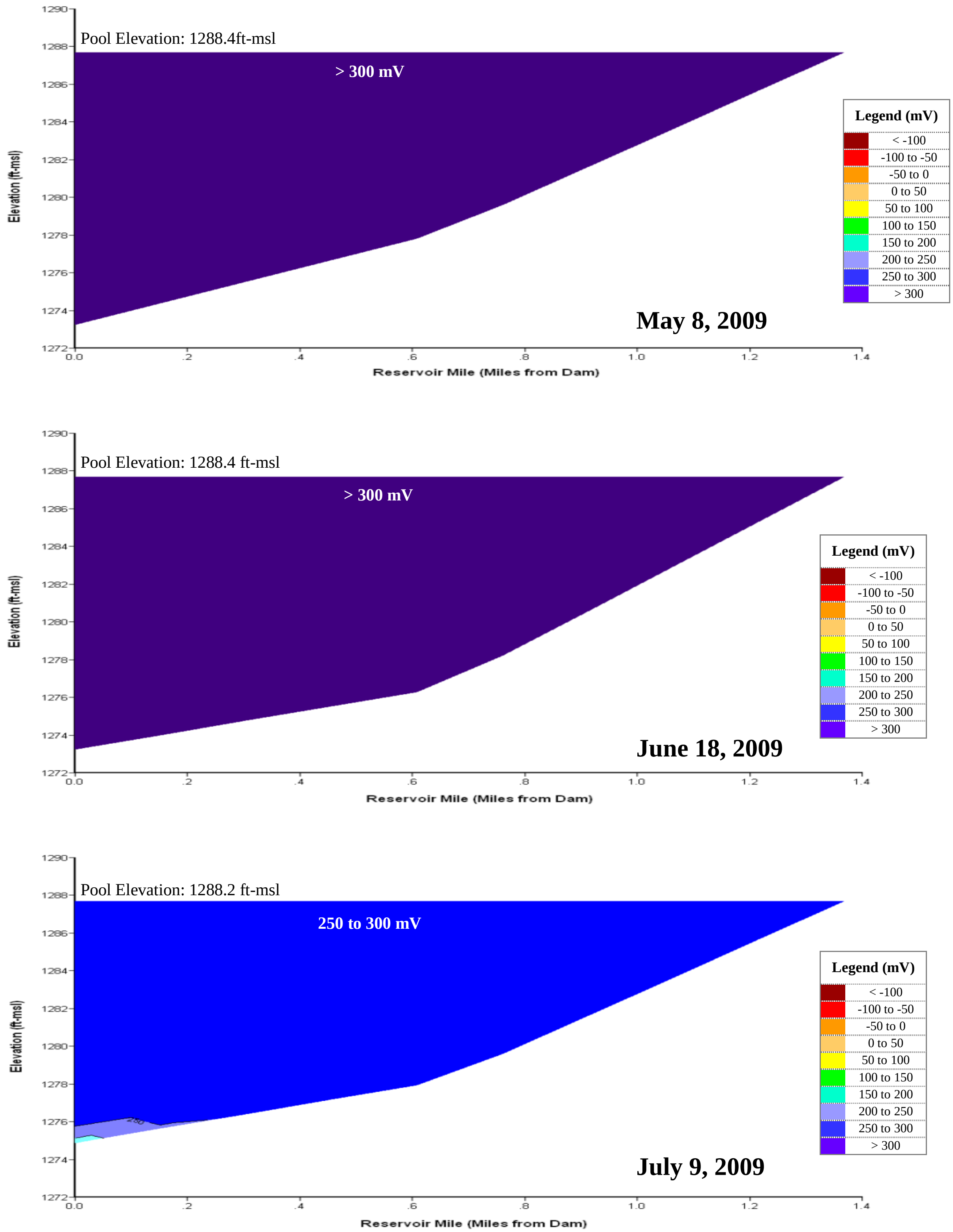
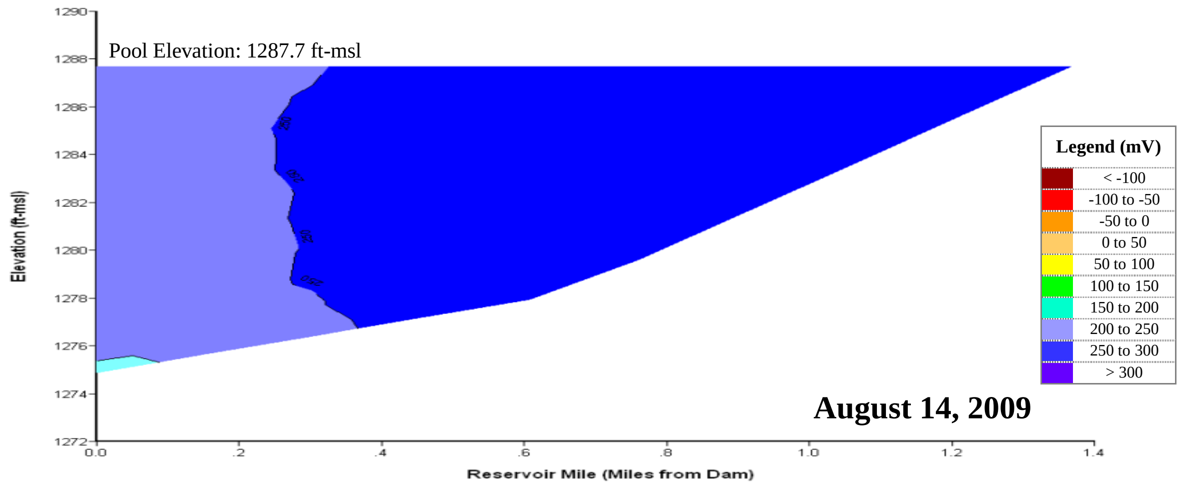


Plate 223. Longitudinal oxidation-reduction potential (mV) contour plots of Wagon Train Reservoir based on depth-profile ORP levels measured at sites WAGLKND1 and WAGLKML1 in 2009.



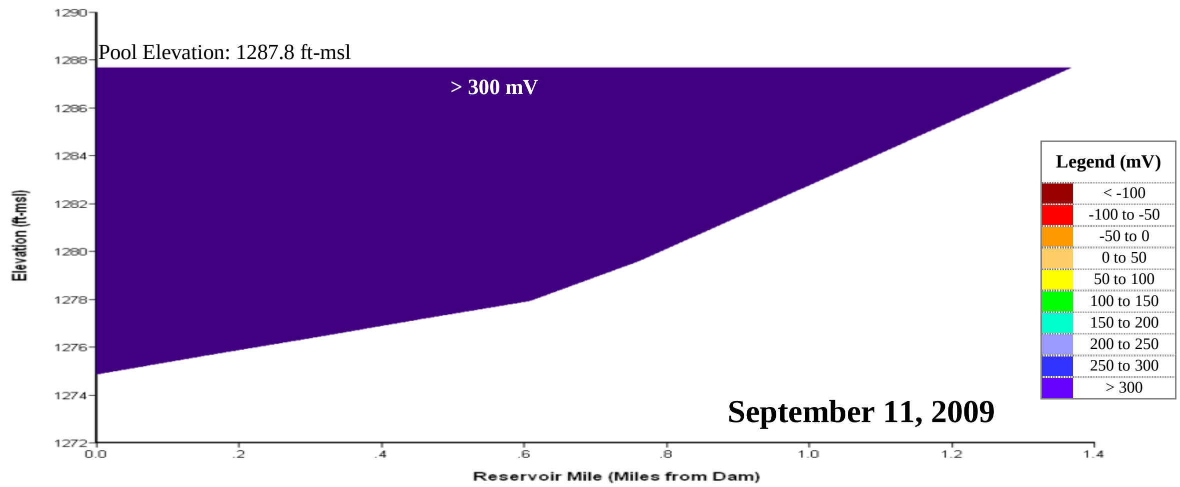


Plate 223. (Continued).

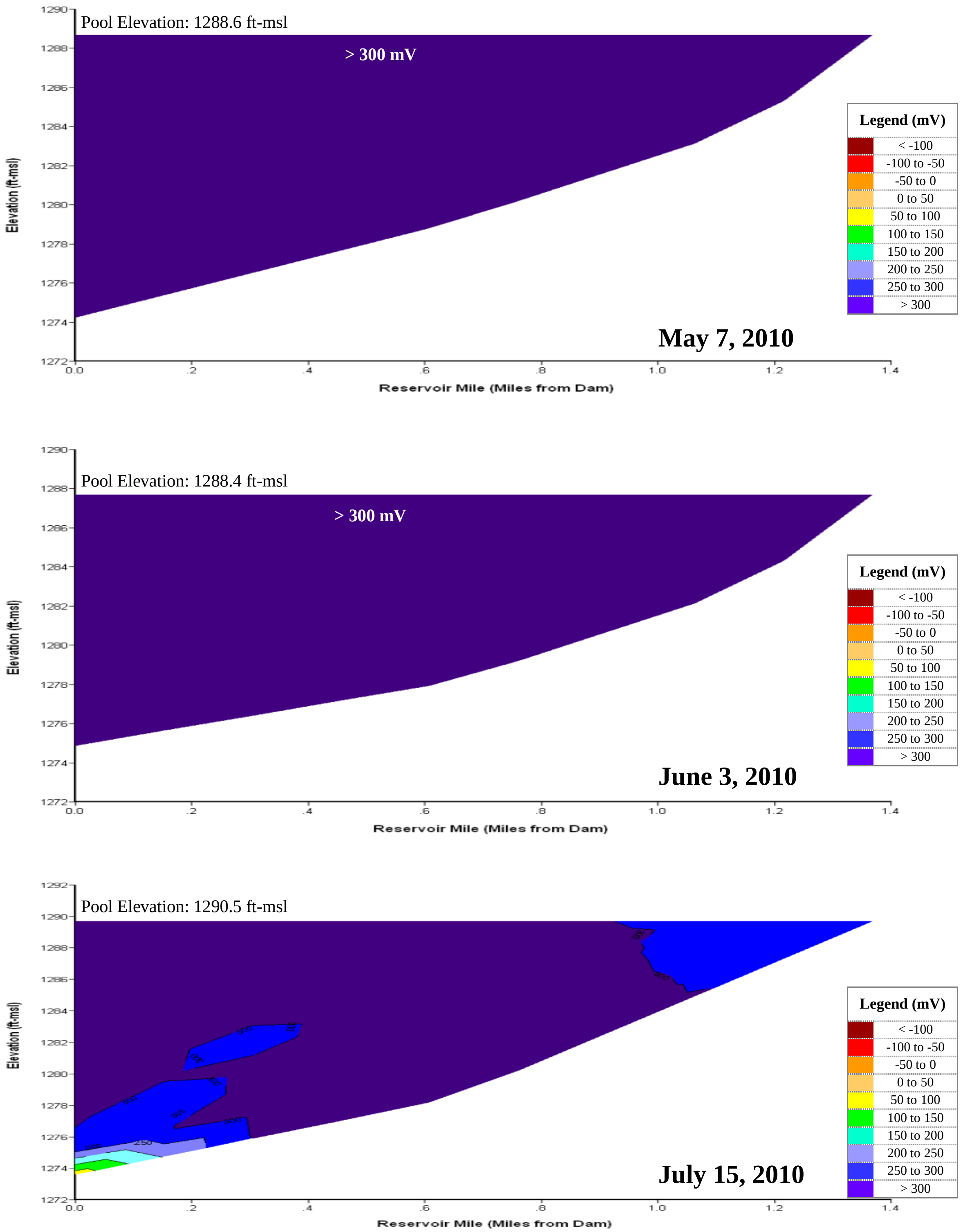
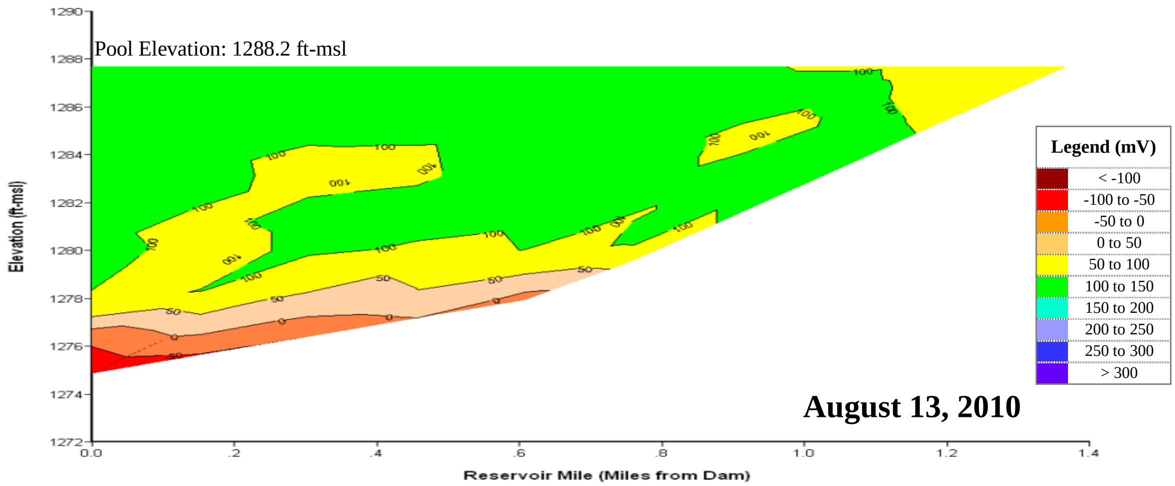


Plate 224. Longitudinal oxidation-reduction potential (mV) contour plots of Wagon Train Reservoir based on depth-profile ORP levels measured at sites WAGLKND1, WAGLKML1, and WAGLKUP1 in 2010.



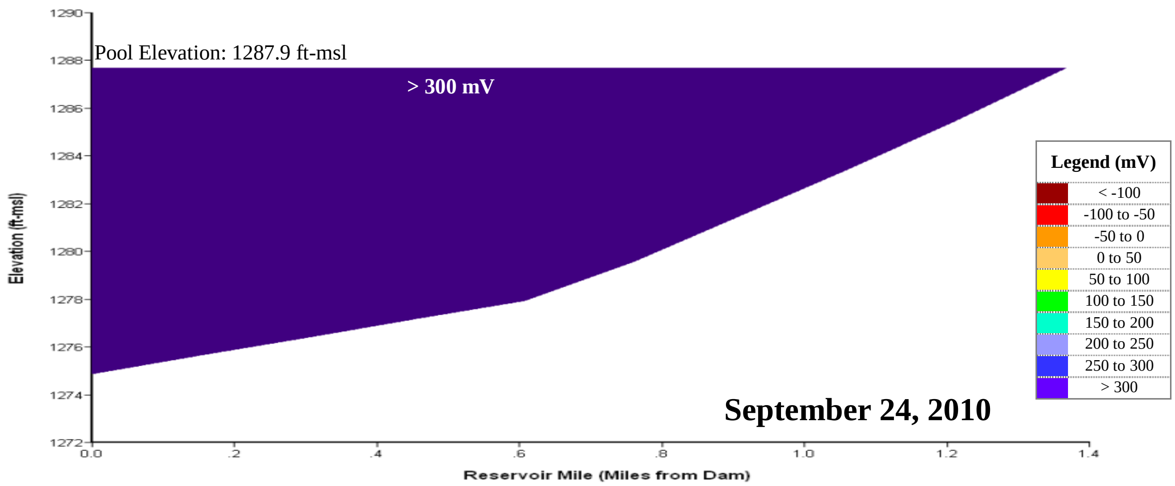


Plate 224. (Continued).

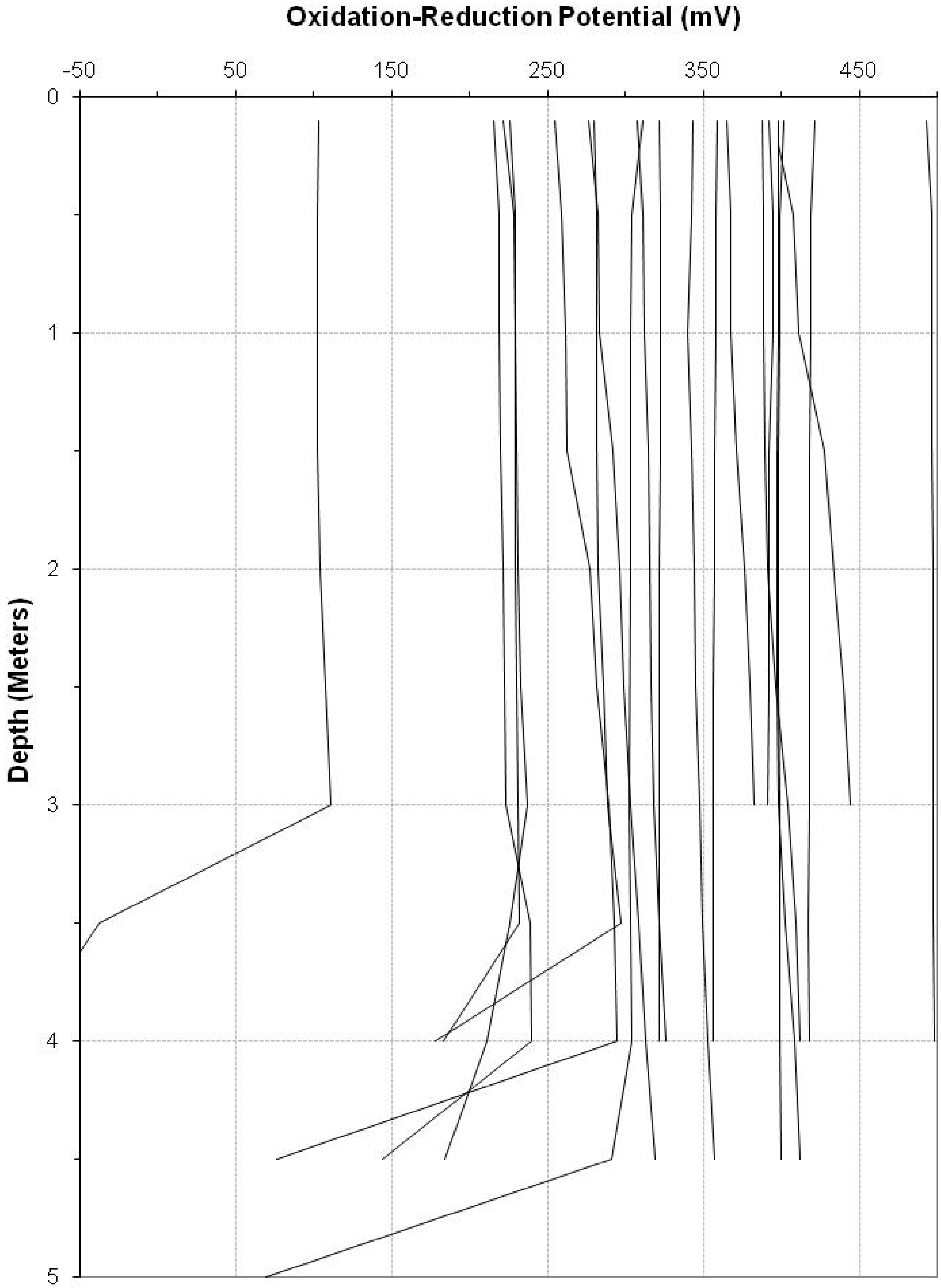
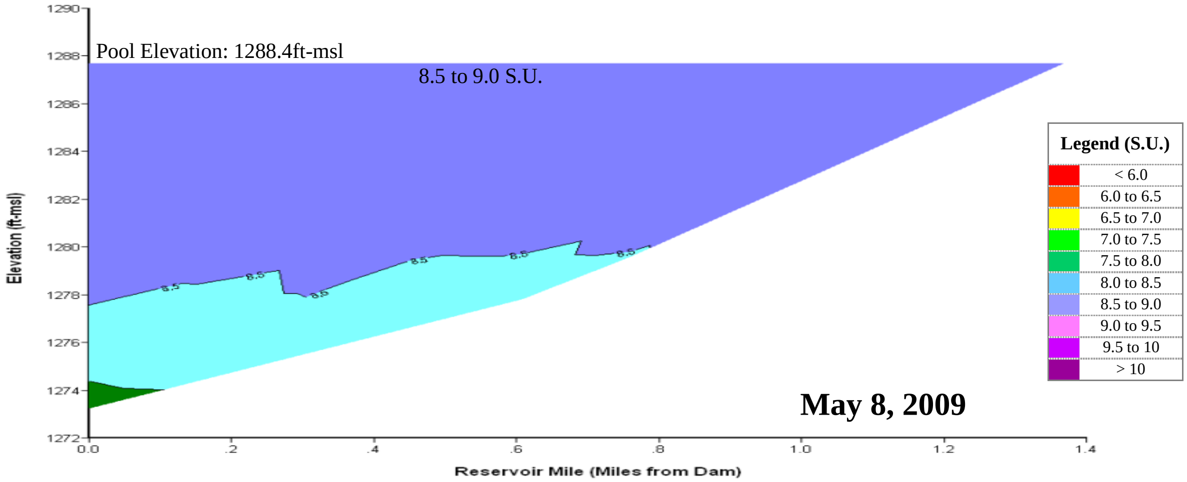
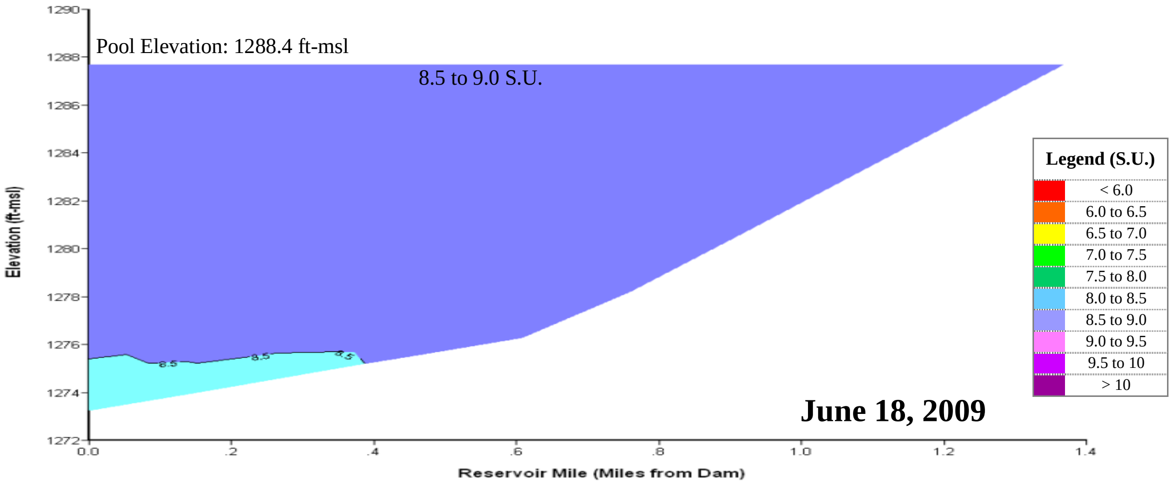


Plate 225. Oxidation-reduction potential depth profiles for Wagon Train Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., WAGLKND1) during the summer over the 5-year period of 2006 through 2010.





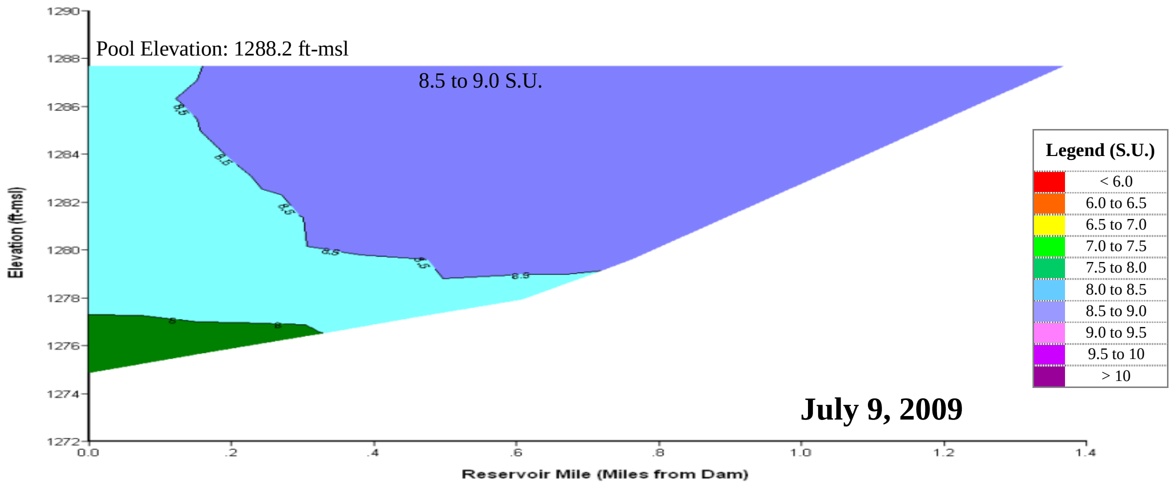
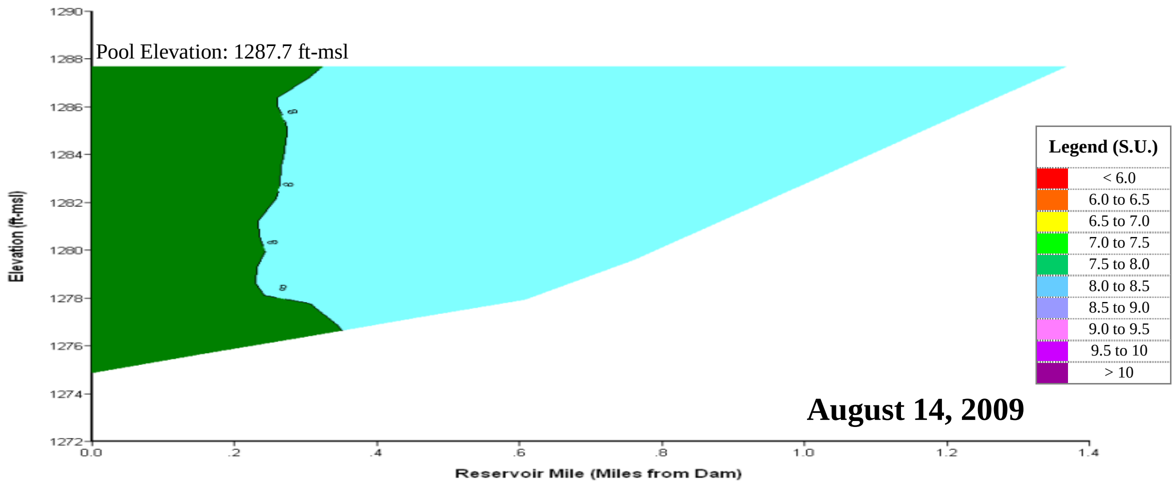


Plate 226. Longitudinal pH (S.U.) contour plots of Wagon Train Reservoir based on depth-profile pH levels measured at sites WAGLKND1 and WAGLKML1 in 2009.



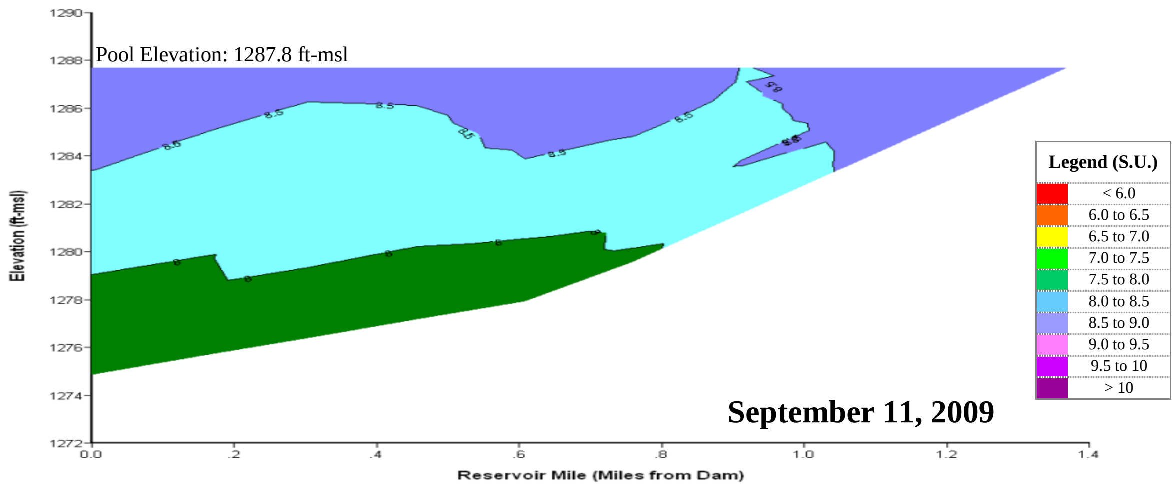
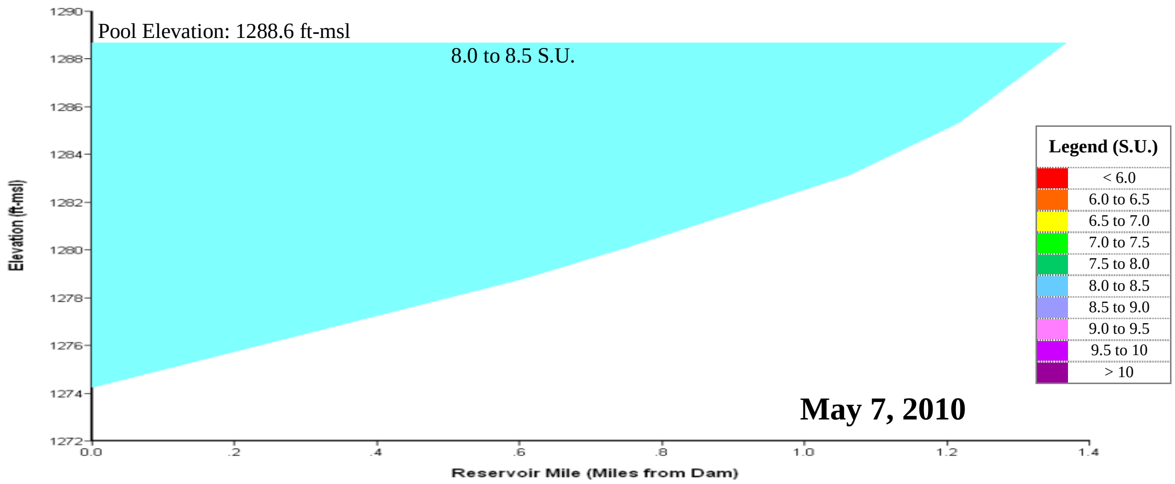
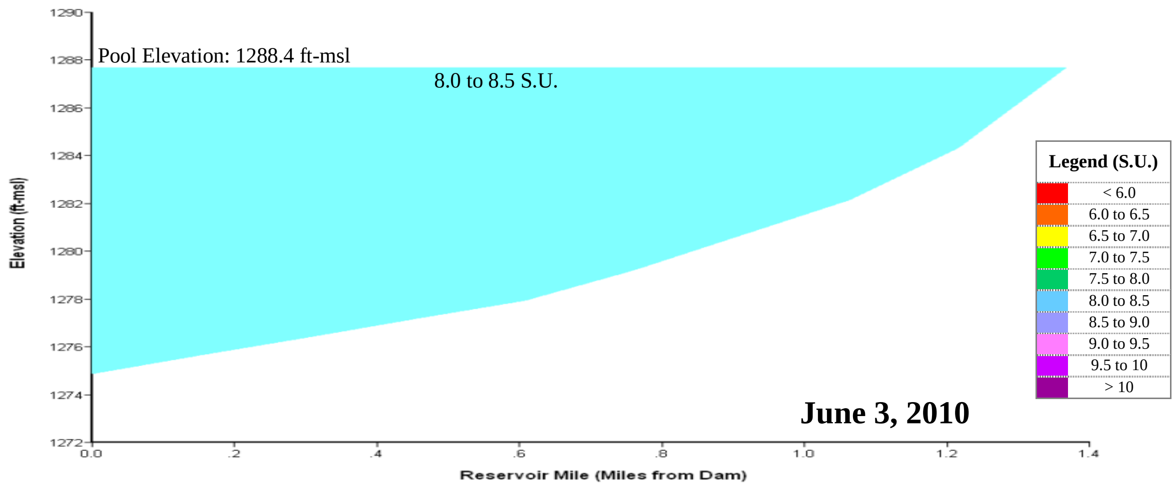


Plate 226. (Continued).





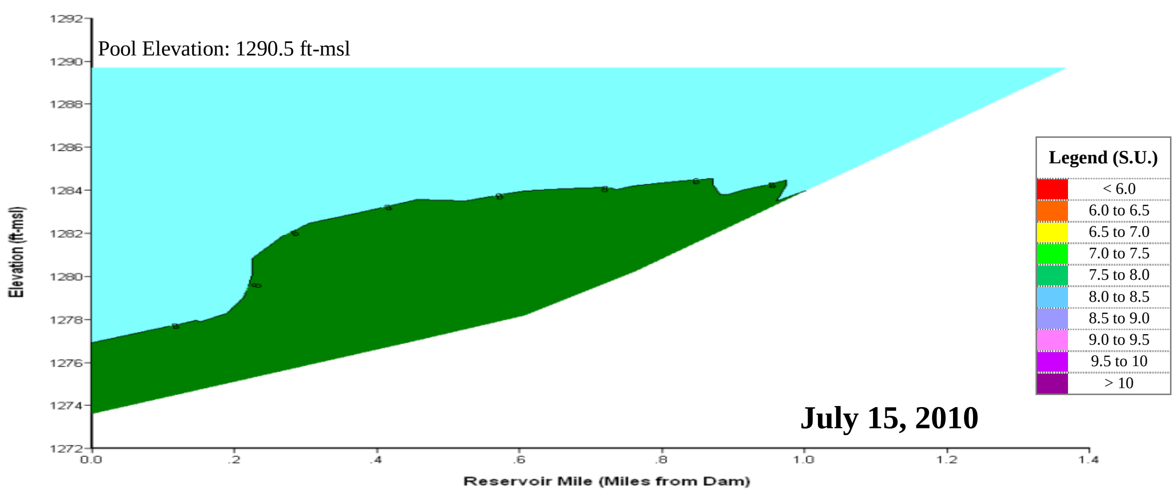
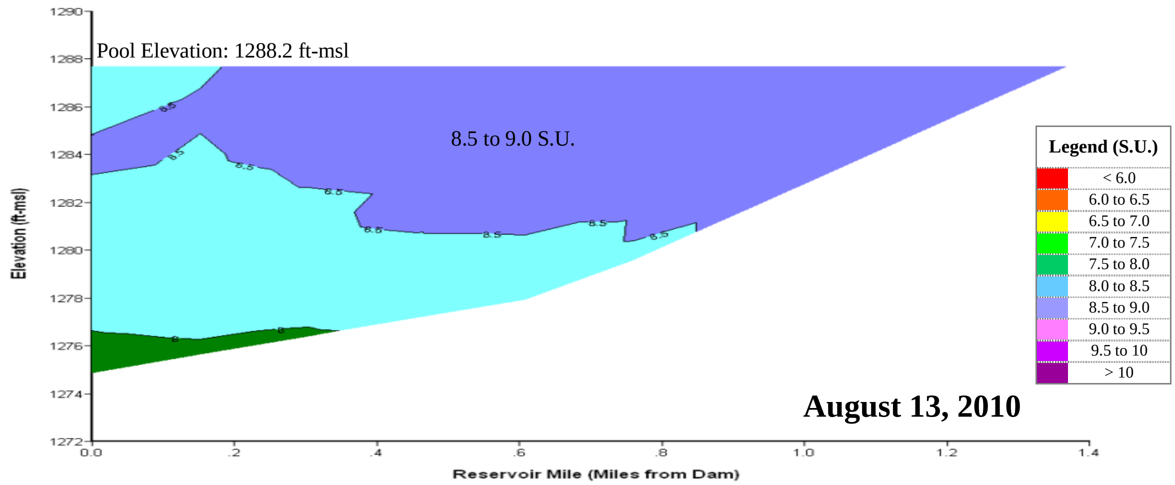


Plate 227. Longitudinal pH (S.U.) contour plots of Wagon Train Reservoir based on depth-profile pH levels measured at sites WAGLKND1, WAGLKML1, and WAGLKUP1 in 2010.



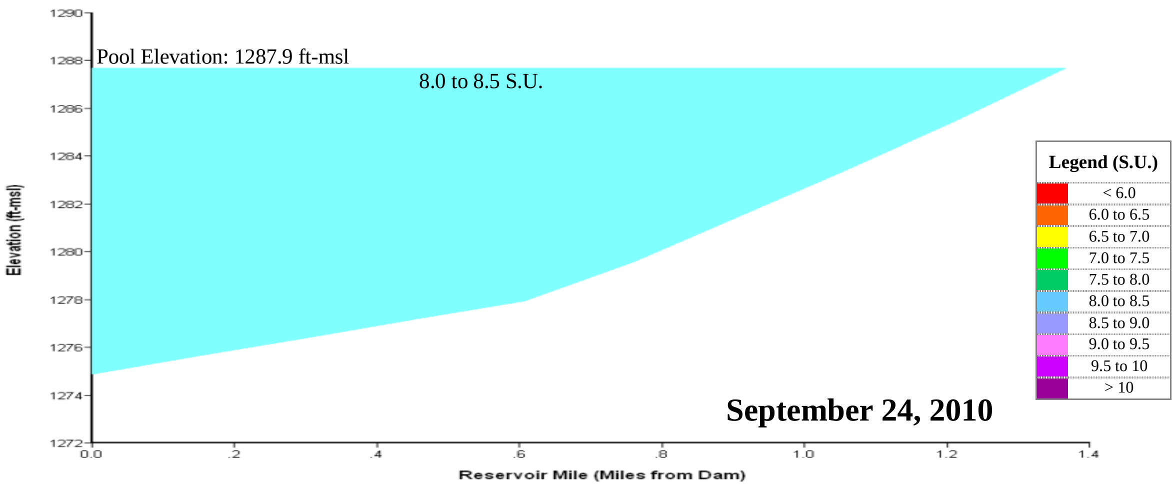


Plate 227. (Continued).

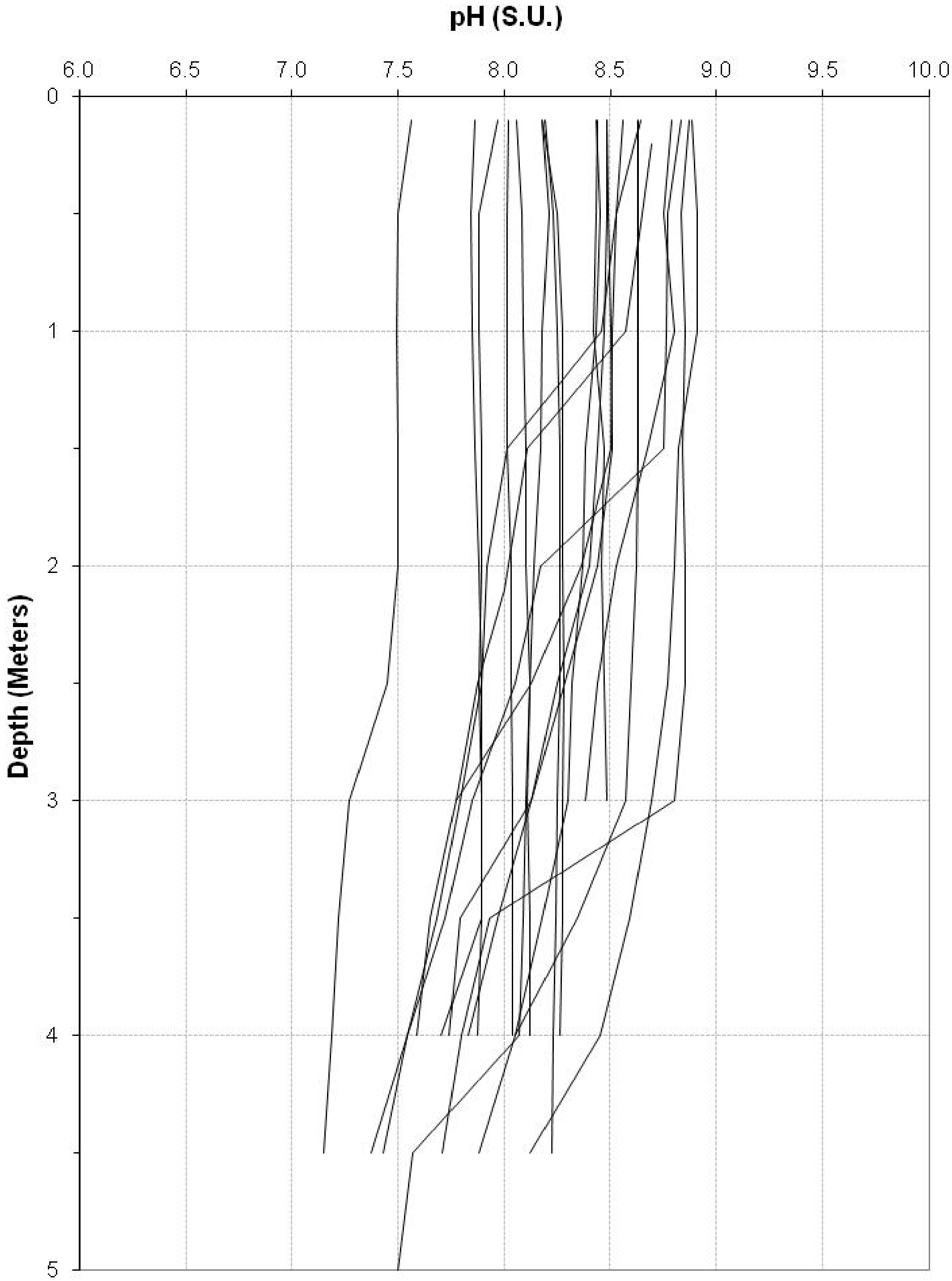


Plate 228. pH depth profiles for Wagon Train Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., WAGLKND1) during the summer over the 5-year period of 2006 through 2010.

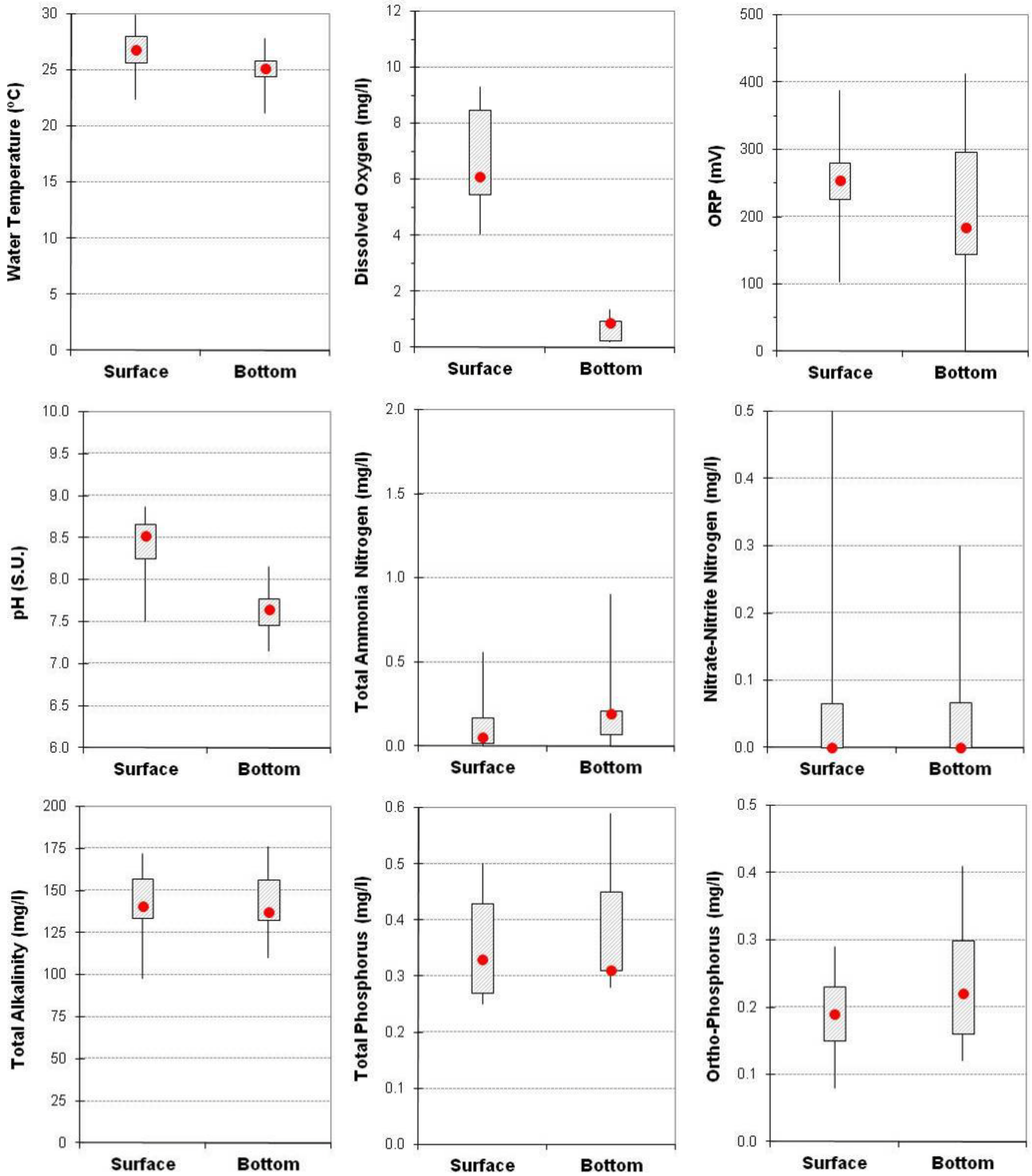
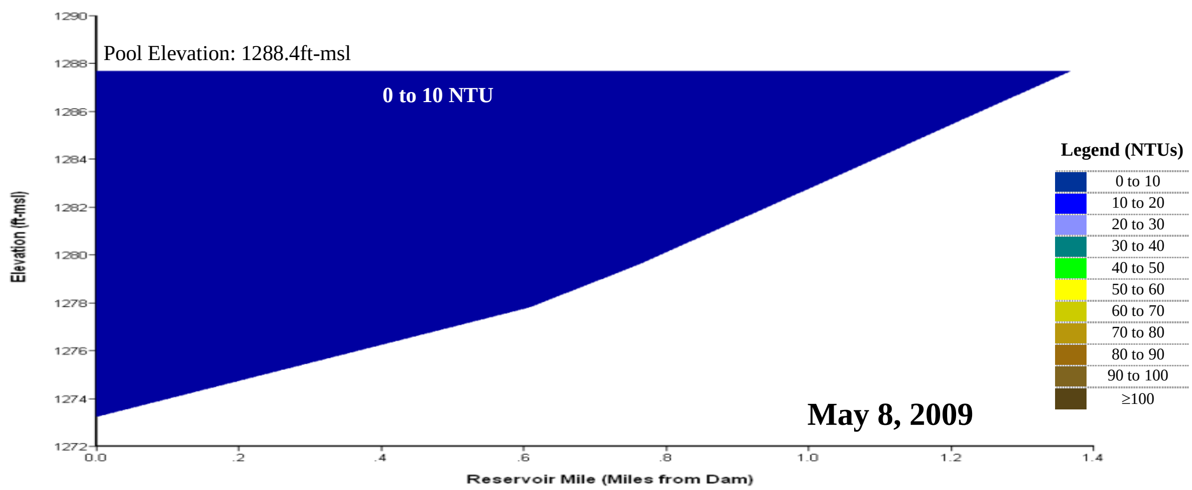
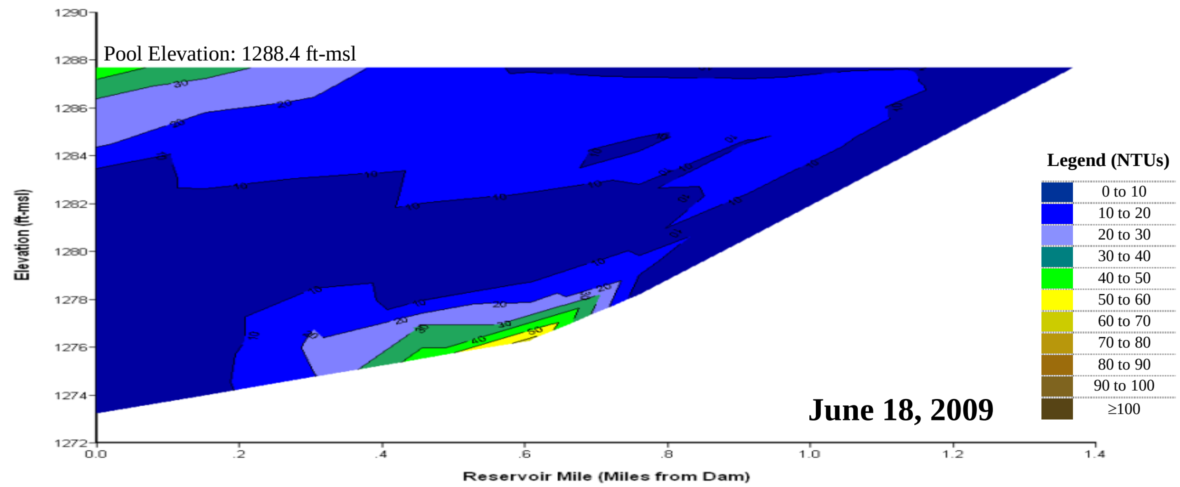


Plate 229. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, alkalinity, total ammonia nitrogen, nitrate-nitrite nitrogen, total phosphorus, and ortho-phosphorus measured in Wagon Train Reservoir when summer hypoxic conditions were present during the 5-year period 2006 through 2010. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)





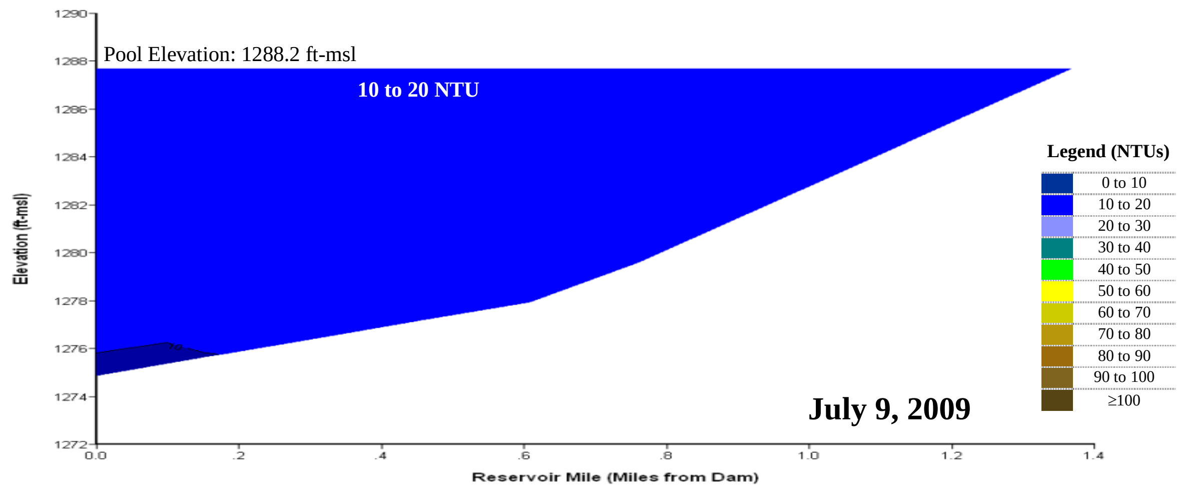
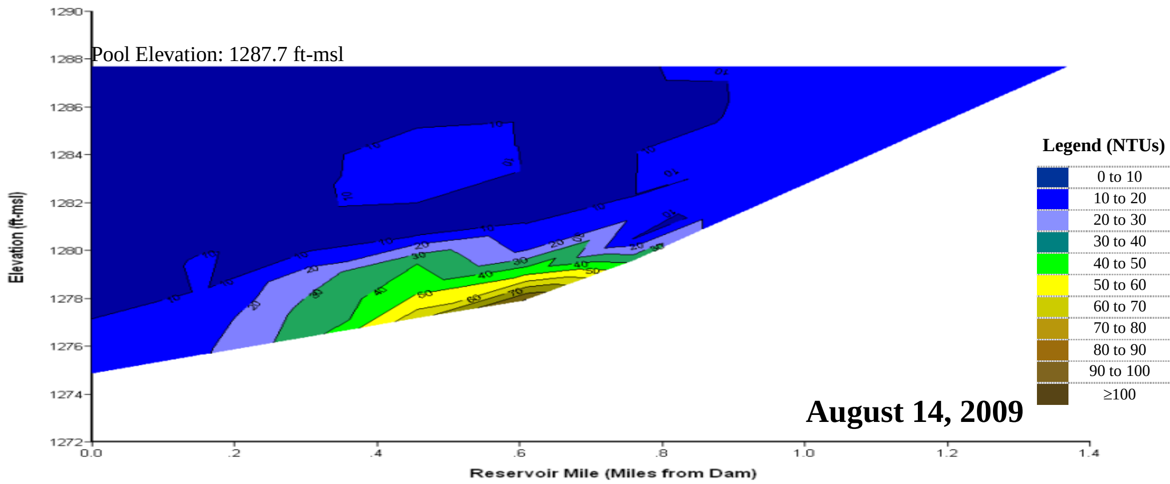


Plate 230. Longitudinal turbidity (NTU) contour plots of Wagon Train Reservoir based on depth-profile turbidity levels measured at sites WAGLKND1 and WAGLKML1 in 2009.



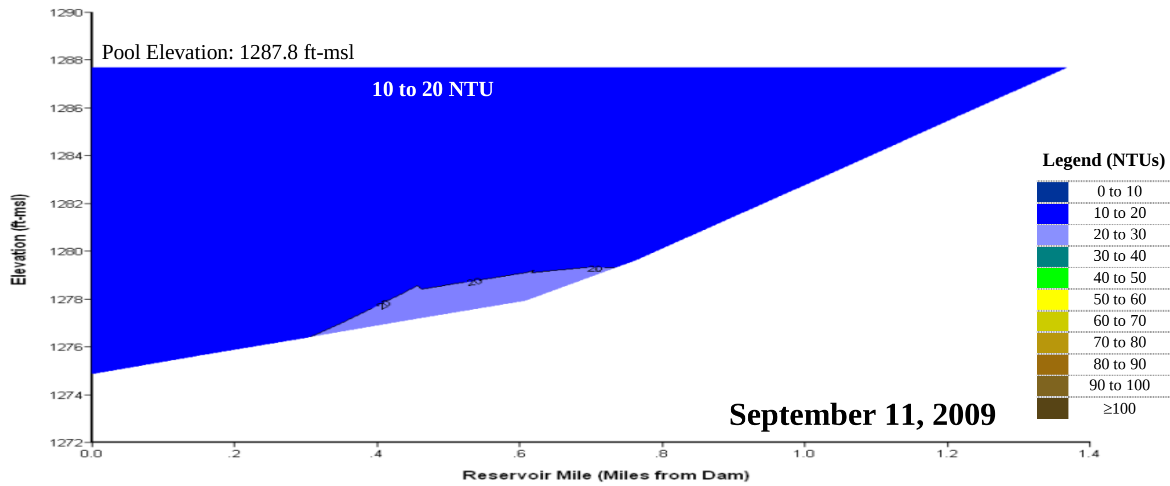


Plate 230. (Continued).

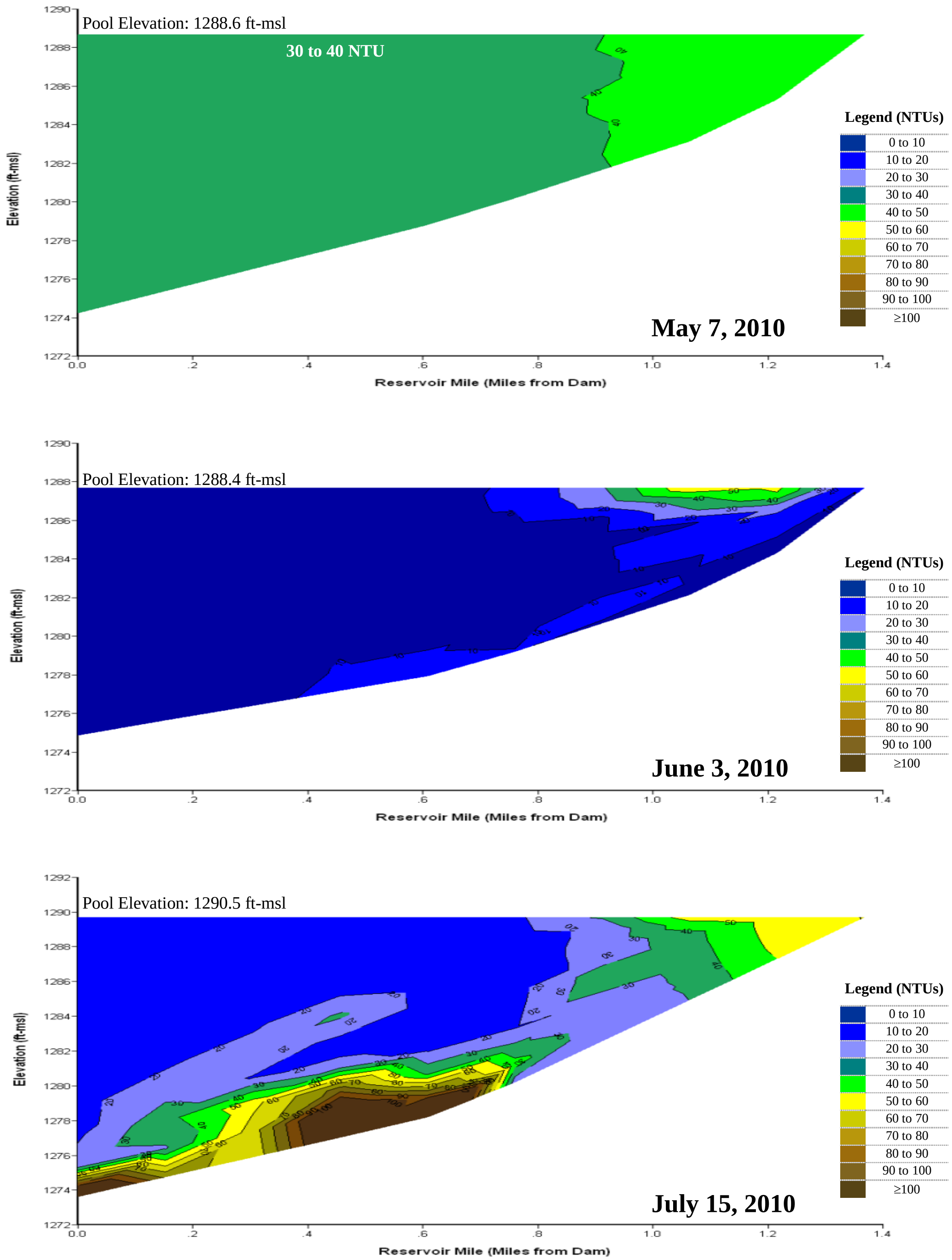
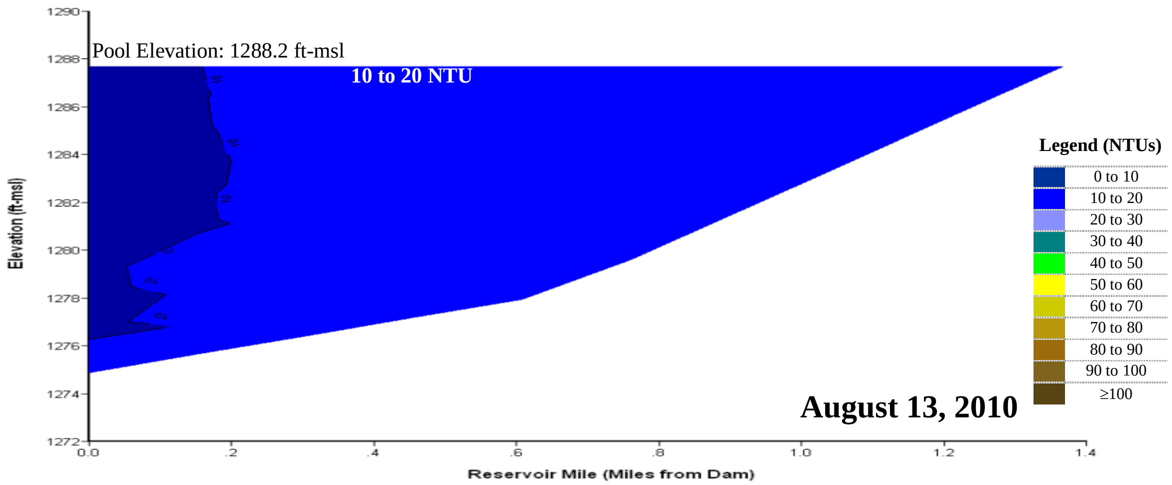


Plate 231. Longitudinal turbidity (NTU) contour plots of Wagon Train Reservoir based on depth-profile turbidity levels measured at sites WAGLKND1, WAGLKML1, and WAGLKUP1 in 2010.



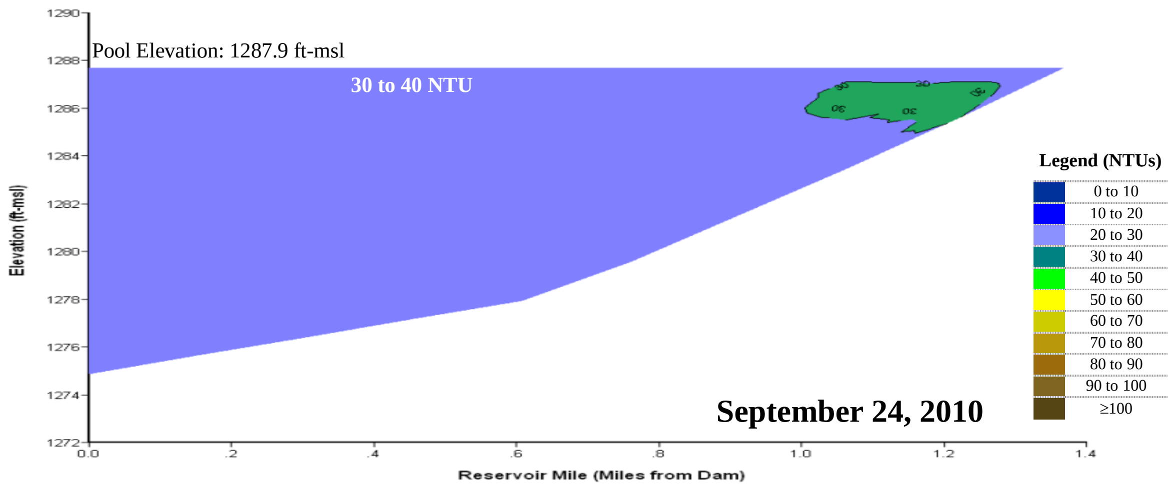


Plate 231. (Continued).

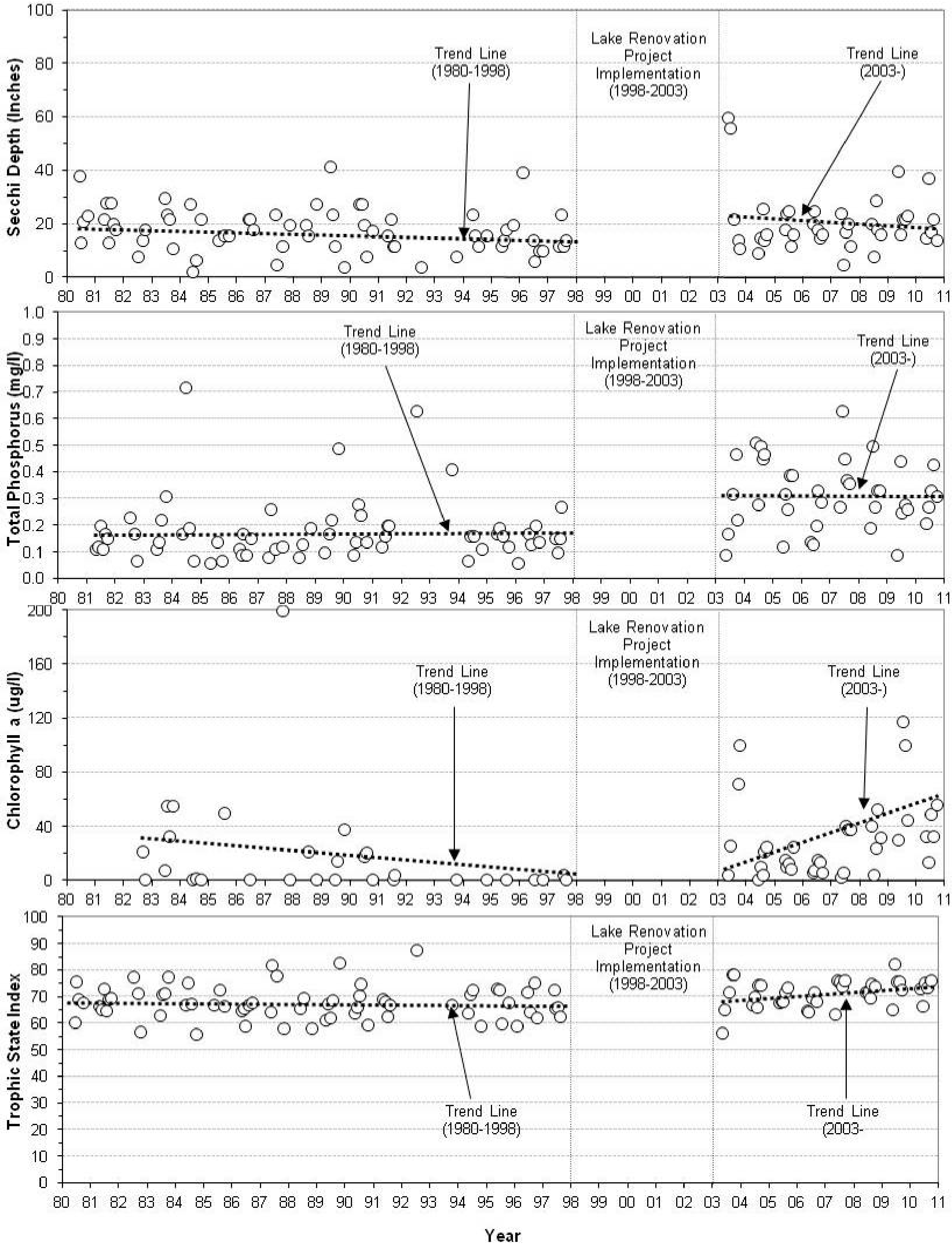


Plate 232. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Wagon Train Reservoir at the near-dam, ambient site (i.e., site WAGLKND1) over the 31-year period of 1980 through 2010.

Plate 233. Summary of runoff water quality conditions monitored in the main tributary inflow to Wagon Train Reservoir at monitoring site WAGNF1 during the 5-year period 2004 through 2008**.** Runoff conditions have not been monitored since 2008.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Kjeldahl N, Total (mg/l)	0.1	11	3.9	4.3	1.6	6.0	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	11	3.83	2.09	0.57	16.22	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	11	1.10	1.02	0.73	1.55	-----	-----	-----
Suspended Solids, Total (mg/l)	4	11	803	446	188	2,850	-----	-----	-----
Acetochlor, Total (ug/l)(C)	0.05	9	4.15	1.87	0.94	14.10	-----	-----	-----
Alachlor, Total (ug/l)(C)	0.05	2	0.52	0.52	0.37	0.67	760(1), 76(2)	0	0%
Atrazine, Total (ug/l)(C)	0.05	12	7.13	3.25	0.27	34.98	330(1), 12(2)	0, 2	0%, 17%
Metolachlor, Total (ug/l)(C)	0.05	12	0.03	1.29	0.11	19.03	390(1), 100(2)	0	0%
E. coli (cfu/100ml)	1	12	14,200	15,900	690	25,000	-----	-----	-----

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Acute criterion for aquatic life.
(2) Chronic criterion for aquatic life.
(C) Immunoassay analysis.

Plate 234. Summary of water quality conditions monitored in Yankee Hill Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site YANLKND1) from May to September during the 4-year period 2007 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	17	1244.8	1244.8	1243.0	1246.3	-----	-----	-----
Water Temperature (°C)	0.1	143	23.5	23.6	16.4	33.2	32(1)	2	1%
Dissolved Oxygen (mg/l)	0.1	143	7.6	7.9	0.2	18.6	≥ 5(2)	29	20%*
Dissolved Oxygen (% Sat.)	0.1	143	94.2	96.2	2.4	272.1	-----	-----	-----
Specific Conductance (umho/cm)	1	143	371	369	121	487	2,000(3)	0	0%
pH (S.U.)	0.1	143	8.3	8.2	6.4	10.0	≥6.5 & ≤9.0(1)	2, 24	18%*
Turbidity (NTUs)	1	143	24	21	2	111	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	143	280	279	-143	486	-----	-----	-----
Secchi Depth (in.)	1	18	25	22	10	39	-----	-----	-----
Alkalinity, Total (mg/l)	7	36	143	146	99	170	20(1)	0	0%
Ammonia, Total (mg/l)	0.02	36	-----	0.09	n.d.	0.78	3.20(4,5), 0.55(4,6)	0, 4	0%, 11%
Chlorophyll *a* (ug/l) – Field Probe	1	140	31	23	2	100	10(7)	98	70%
Chlorophyll *a* (ug/l) – Lab Determined	1	18	47	43	11	128	10(7)	18	100%
Hardness, Total (mg/l)	0.4	4	136.3	144.5	98.0	158.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.10	36	1.7	1.6	0.8	3.8	-----	-----	-----
Nitrogen, Total (mg/)	0.10	36	1.8	1.7	0.8	3.8	1 (7)	35	97%
Nitrate-Nitrite N, Total (mg/l)	0.02	36	-----	0.00	n.d.	0.70	100(3)	-----	-----
Phosphorus, Total (mg/l)	0.10	36	0.3	0.3	0.1	0.7	0.05(7)	16	100%
Phosphorus-Ortho, Dissolved (mg/l)		36	0.16	0.13	0.02	0.47	-----	-----	-----
Suspended Solids, Total (mg/l)	4	30	18	17	4	79	-----	-----	-----
Aluminum, Dissolved (ug/l)	25	4	-----	n.d.	n.d.	n.d.	750(5), 87(6)	0	0%
Antimony, Dissolved (ug/l)	0.5	4	-----	n.d.	n.d.	n.d.	88(5), 30(6)	0	0%
Arsenic, Dissolved (ug/l)	1	4	10	9	8	13	340(5), 16.7(8)	0	0%
Beryllium, Dissolved (ug/l)	2	4	-----	n.d.	n.d.	n.d.	130(5), 5.3(6)	0	0%
Cadmium, Dissolved (ug/l)	0.2	4	-----	n.d.	n.d.	n.d.	8.4(5), 0.3(6)	0	0%
Chromium, Dissolved (ug/l)	10	4	-----	n.d.	n.d.	4	800(5), 104(6)	0	0%
Copper, Dissolved (ug/l)	2	4	-----	n.d.	n.d.	3	19(5), 12(6)	0	0%
Lead, Dissolved (ug/l)	0.5	2	-----	n.d.	n.d.	n.d.	96(5), 3.8(6)	0	0%
Mercury, Dissolved (ug/l)	0.05	4	-----	n.d.	n.d.	n.d.	1.4(5)	0	0%
Mercury, Total (ug/l)	0.05	4	-----	n.d.	n.d.	n.d.	0.77(6)	0	0%
Nickel, Dissolved (ug/l)	10	4	-----	n.d.	n.d.	n.d.	639(5), 71(6)	0	0%
Selenium, Total (ug/l)	1	4	-----	1	n.d.	14	20(3,5), 5(6)	0, 1	0%, 25%
Silver, Dissolved (ug/l)	1	4	-----	n.d.	n.d.	n.d.	6.5(5)	0	0%
Thallium (ug/l)	0.5	4	-----	n.d.	n.d.	n.d.	1,400(5), 6.3(8)	0	0%
Zinc, Dissolved (ug/l)	10	4	-----	n.d.	n.d.	n.d.	160(5,6)	0	0%
Microcystin, Total (ug/l)	0.05	18	-----	n.d.	n.d.	0.46	20(9)	0	0%
Acetochlor, Total (ug/l)(C)	0.05	15	-----	0.30	n.d.	1.30	-----	-----	-----
Alachlor, Total (ug/l)(C)	0.05	3	-----	0.10	n.d.	0.30	760(5), 76(6)	0	0%
Atrazine, Total (ug/l)(C)	0.05	18	3.28	2.40	1.00	9.90	330(5), 12(6)	0	0%
Metolachlor, Total (ug/l)(C)	0.05	18	-----	0.30	n.d.	2.40	390(5), 100(6)	0	0%
Pesticide Scan (ug/l)(D)	0.01 - 0.13	3					-----	-----	-----
Atrazine	0.13		-----	1.1	n.d.	3.2	330(5), 12(6)	0	0%
Dethylatrazine	0.05		-----	0.60	n.d.	1.20	-----	-----	-----
Deisopropylatrazine	0.08		-----	n.d.	n.d.	0.20	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l microcystins in recreation water for impairment assessment.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 235. Summary of water quality conditions monitored in Yankee Hill Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site YANLKMLS1) from May to September during the 4-year period 2007 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, and ORP are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	17	1244.8	1244.9	1243.0	1246.3	-----	-----	-----
Water Temperature (°C)	0.1	111	24.2	24.9	16.2	32.7	32(1)	2	2%
Dissolved Oxygen (mg/l)	0.1	112	8.4	7.7	0.5	22.5	≥ 5(2)	13	12%
Dissolved Oxygen (% Sat.)	0.1	112	105.8	94.2	6.7	318.9	-----	-----	-----
Specific Conductance (umho/cm)	1	112	371	366	254	477	2,000(3)	0	0%
pH (S.U.)	0.1	112	8.4	8.3	6.8	10.1	≥6.5 & ≤9.0(1)	23	21%*
Turbidity (NTUs)	1	112	21	17	2	80	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	112	295	292	-82	476	-----	-----	-----
Secchi Depth (in.)	1	18	24	23	12	38	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	112	34	24	2	105	10(4)	82	73%

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 236. Summary of water quality conditions monitored in Yankee Hill Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site YANLKMLW1) from May to September during the 4-year period 2007 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, and ORP are for water column depth-profile measurements.]

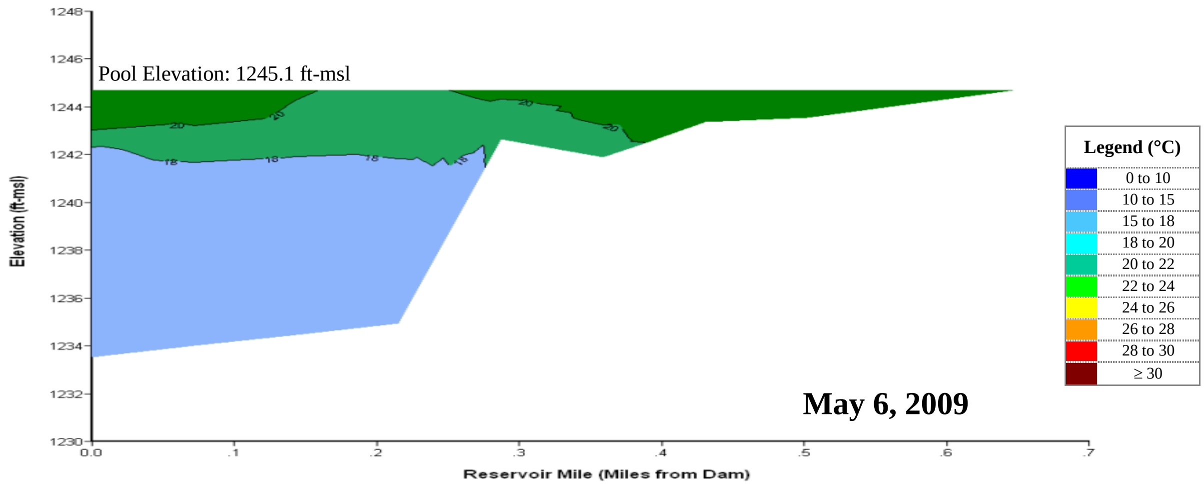
Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	17	1244.8	1244.9	1243.0	1246.3	-----	-----	-----
Water Temperature (°C)	0.1	105	24.3	25.6	16.7	33.7	32(1)	2	2%
Dissolved Oxygen (mg/l)	0.1	105	8.7	8.3	0.7	21.8	≥ 5(2)	10	10%
Dissolved Oxygen (% Sat.)	0.1	105	109.9	104.0	9.5	304.9	-----	-----	-----
Specific Conductance (umho/cm)	1	105	373	382	255	477	2,000(3)	0	0%
pH (S.U.)	0.1	105	8.5	8.3	7.1	10.1	≥6.5 & ≤9.0(1)	20	19%*
Turbidity (NTUs)	1	105	21	20	3	101	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	105	304	289	-78	477	-----	-----	-----
Secchi Depth (in.)	1	18	24	23	8	38	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	103	32	22	4	99	10(4)	82	80%

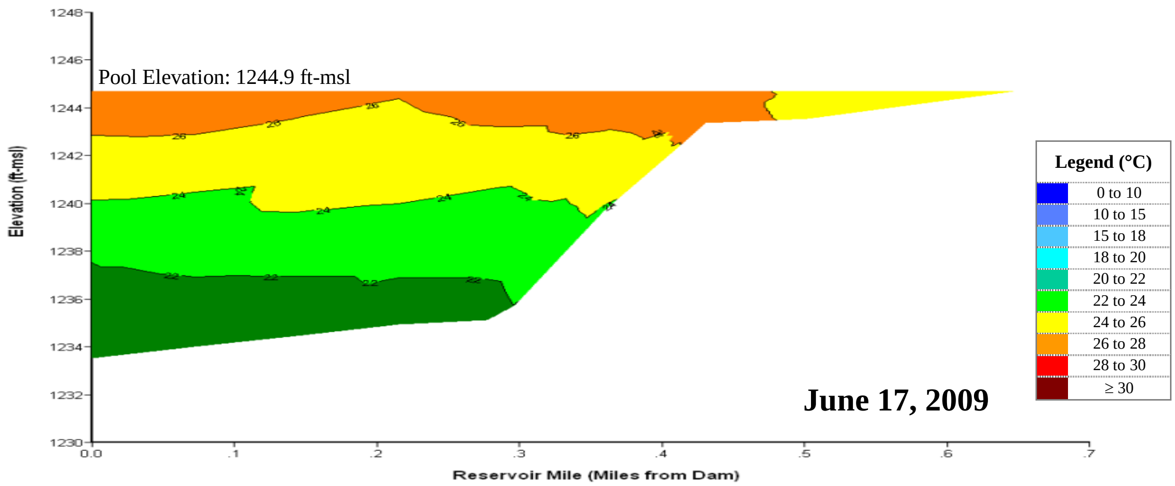
n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.

* A highlighted mean or percent exceedence indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.





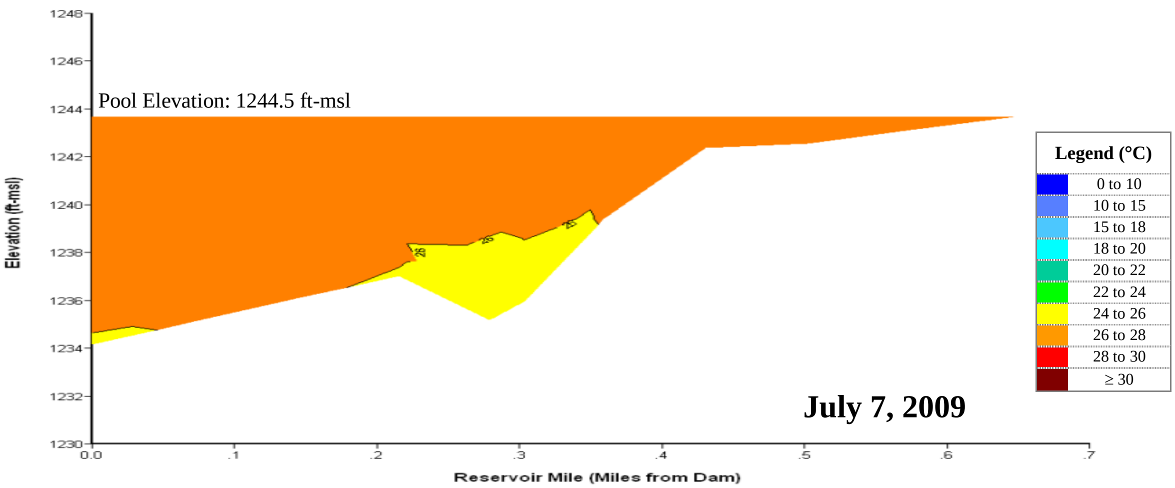
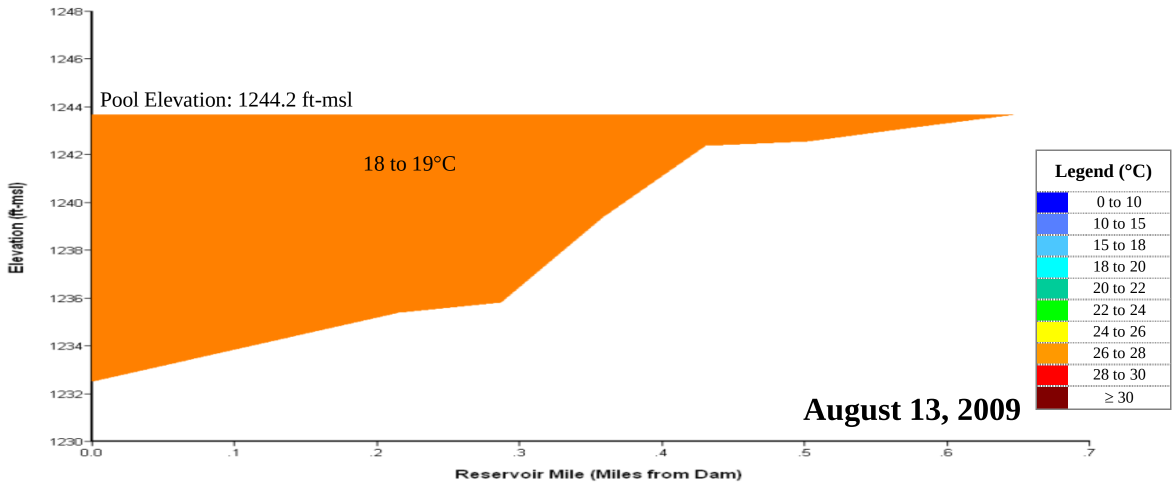


Plate 237. Longitudinal water temperature (°C) contour plots of Yankee Hill Reservoir based on depth-profile water temperatures measured at sites YANLKND1 and YANLKMLS1 in 2009.



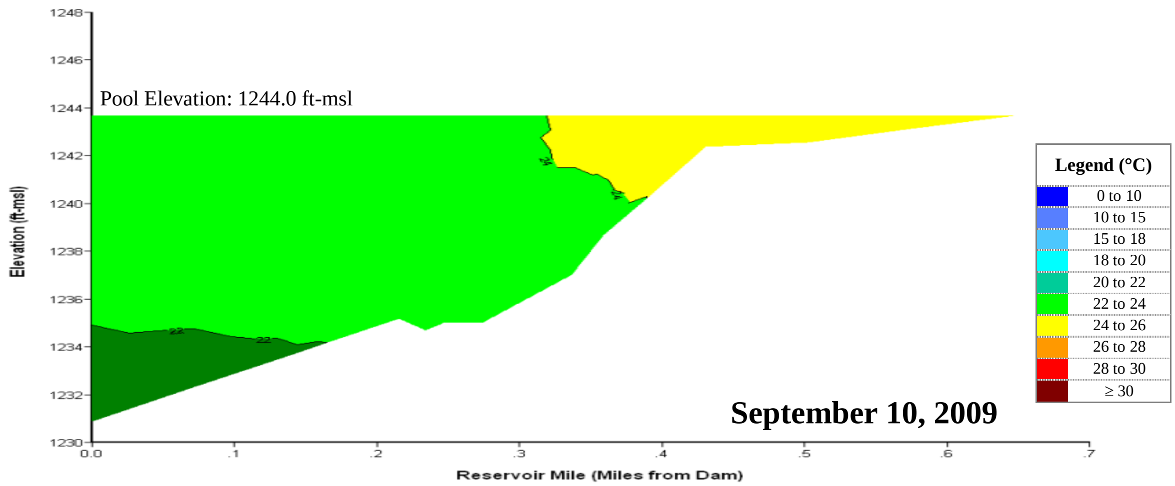


Plate 237. (Continued).

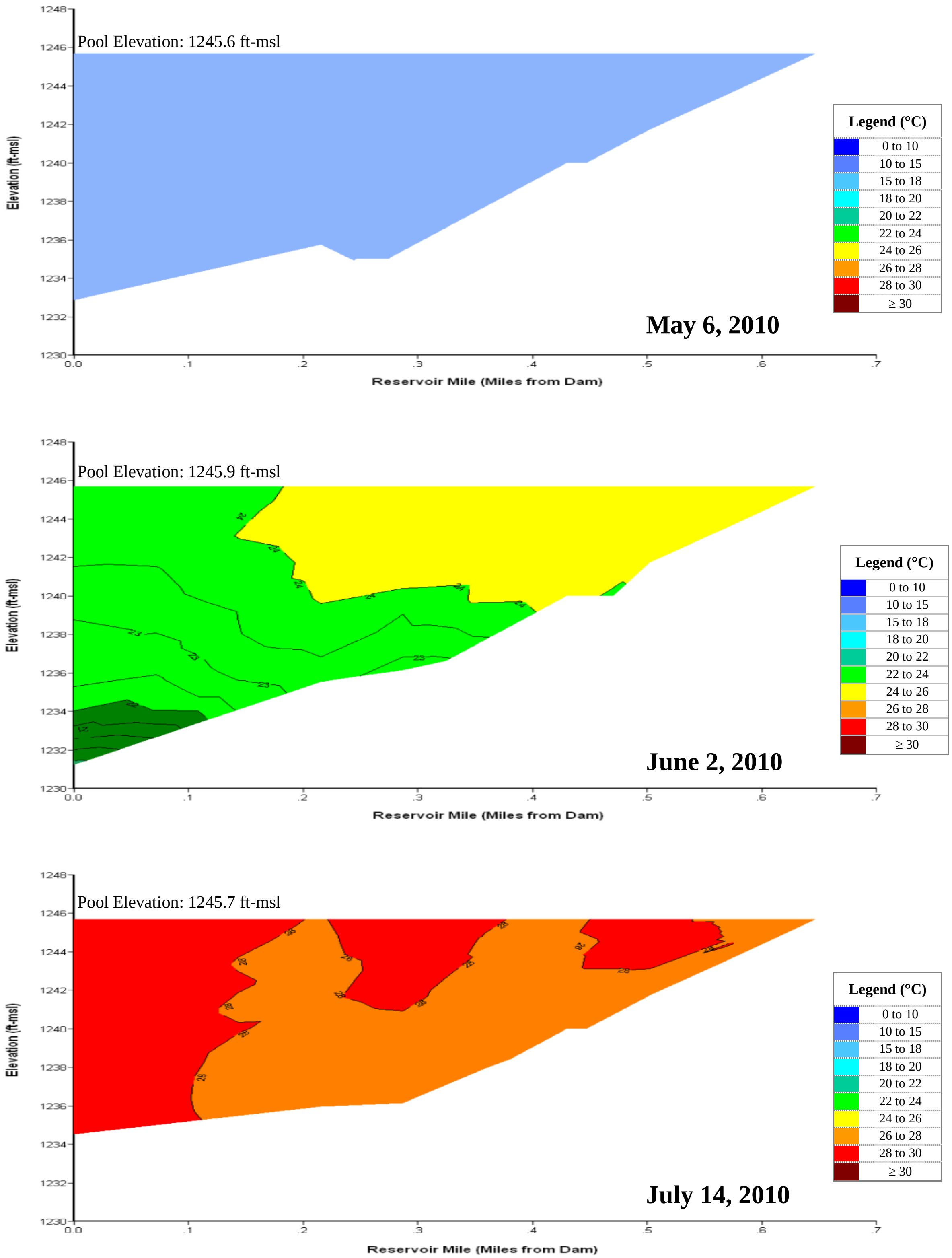
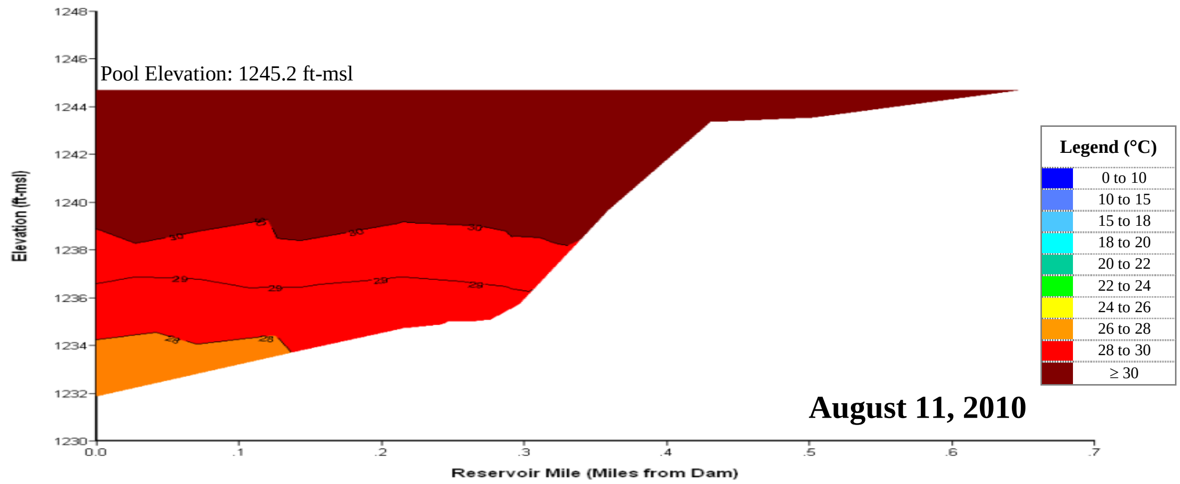


Plate 238. Longitudinal water temperature (°C) contour plots of Yankee Hill Reservoir based on depth-profile water temperatures measured at sites YANLKND1, YANLKMLS1, and YANLKUPS1 in 2010.



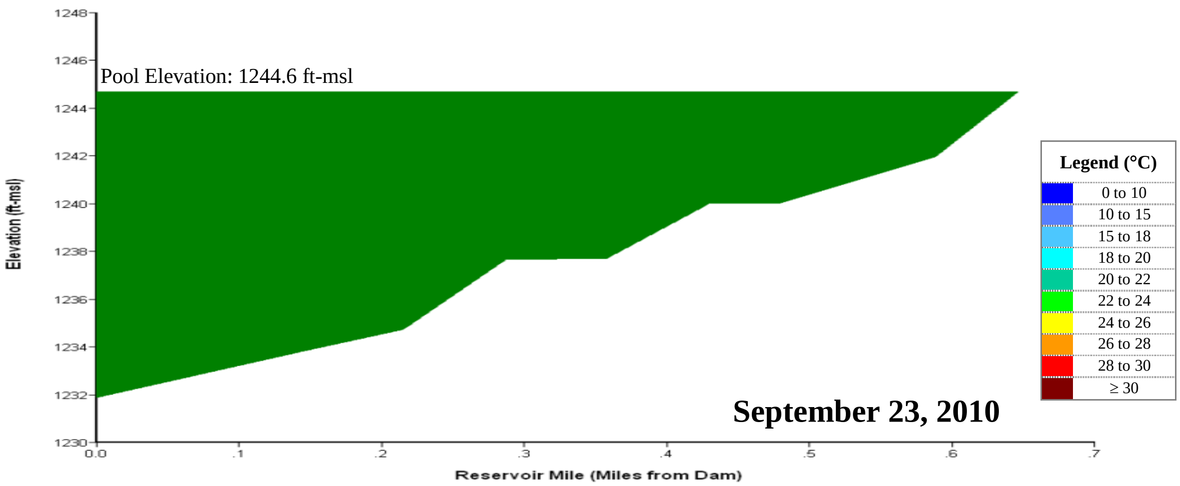


Plate 238. (Continued).

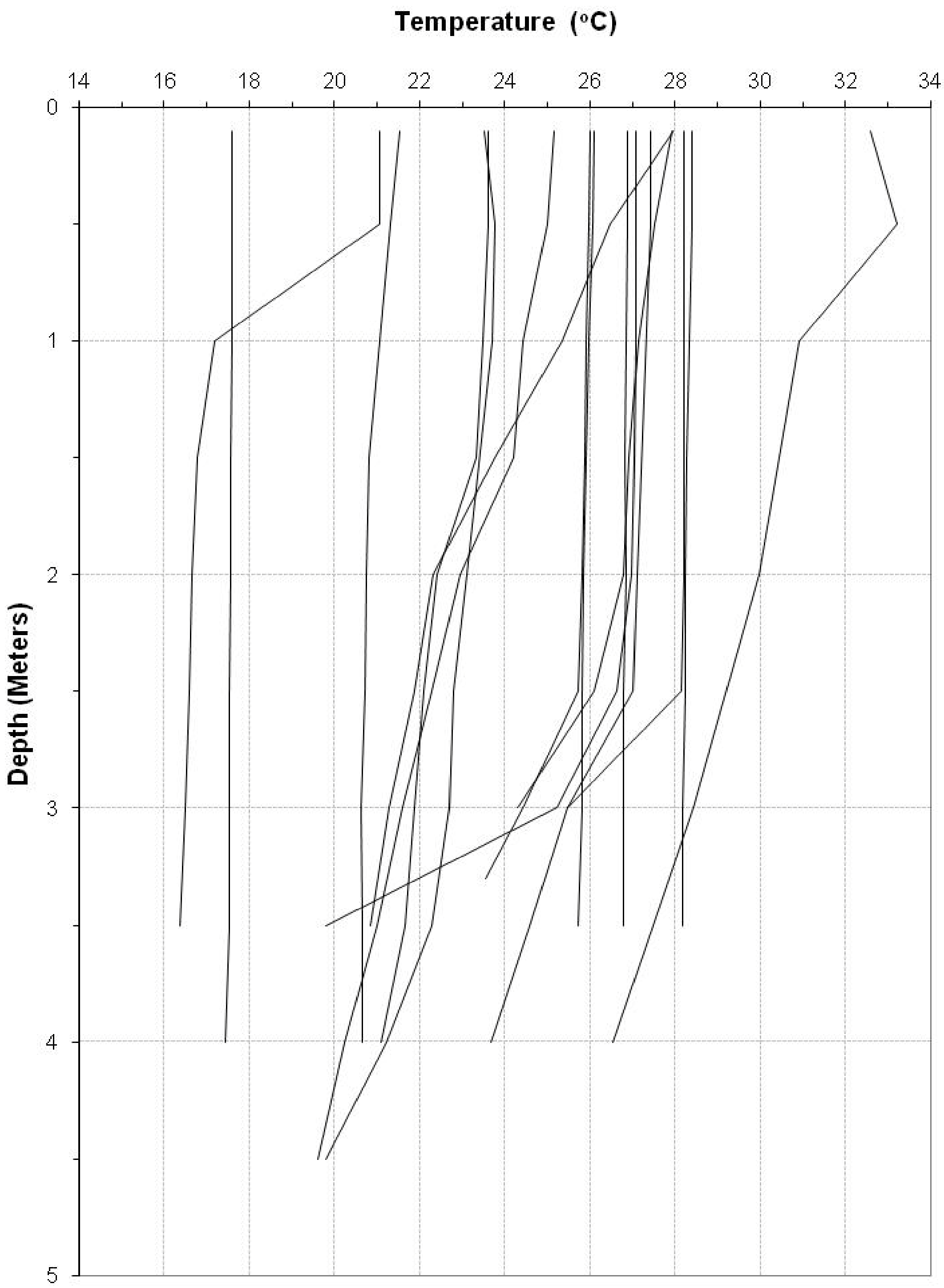
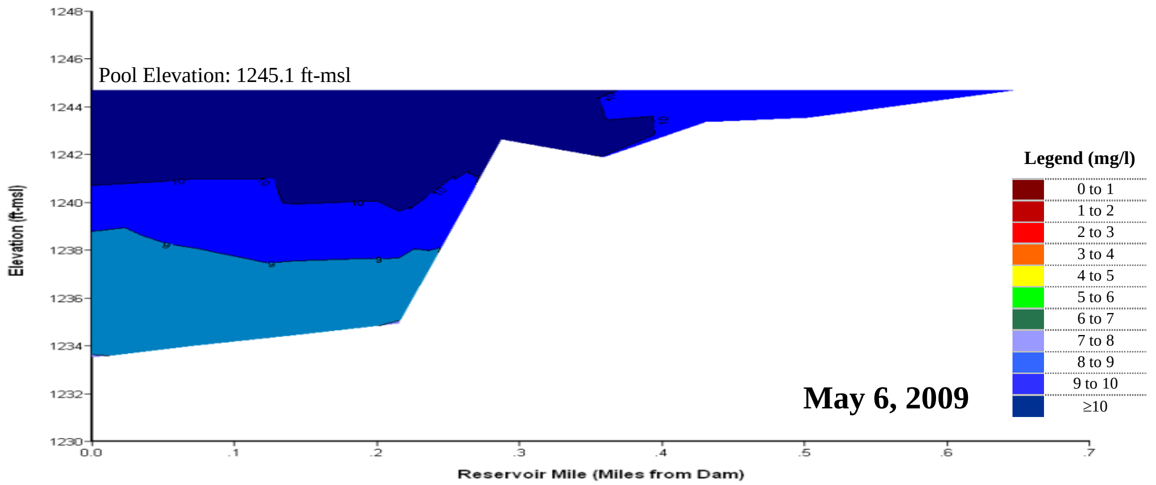
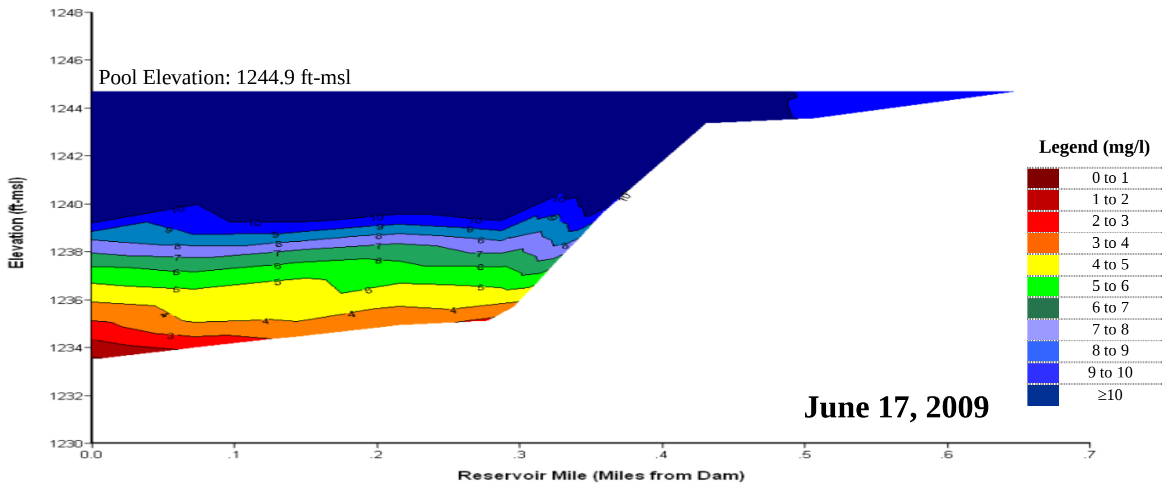


Plate 239. Temperature depth profiles for Yankee Hill Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., YANLKND1) during the summer over the 4-year period of 2007 through 2010.





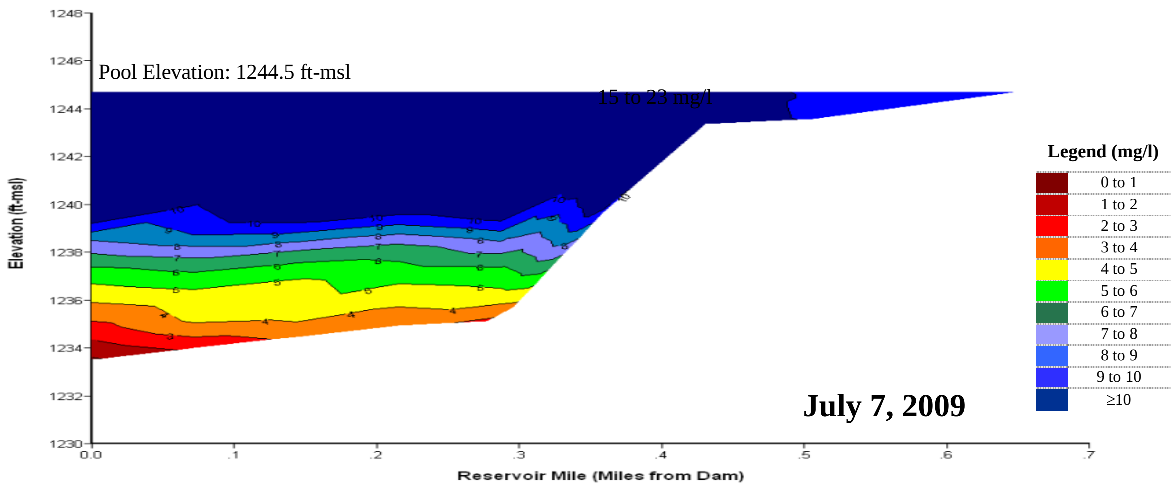
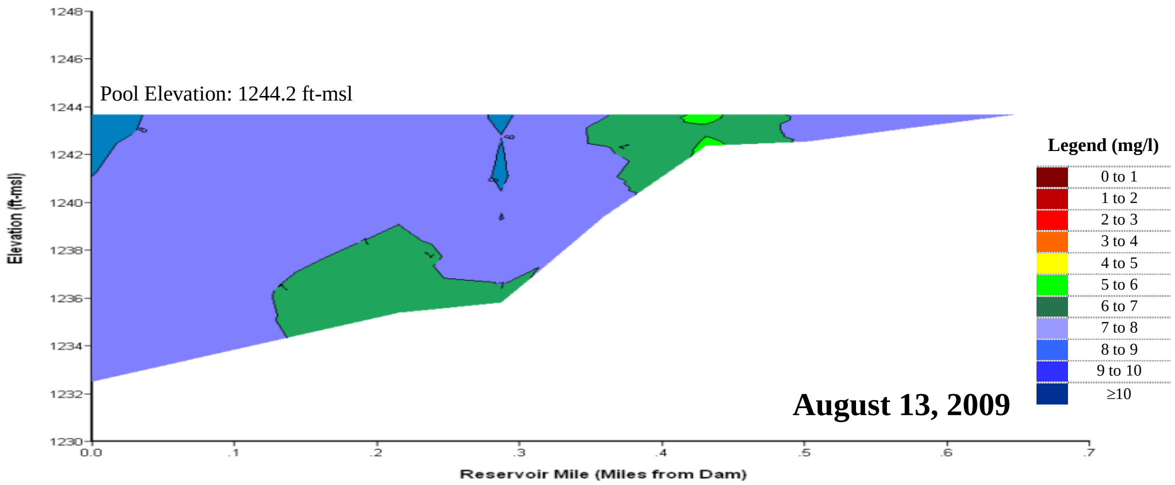


Plate 240. Longitudinal dissolved oxygen (mg/l) contour plots of Yankee Hill Reservoir based on depth-profile dissolved oxygen concentrations measured at sites YANLKND1 and YANLKMLS1 in 2009.



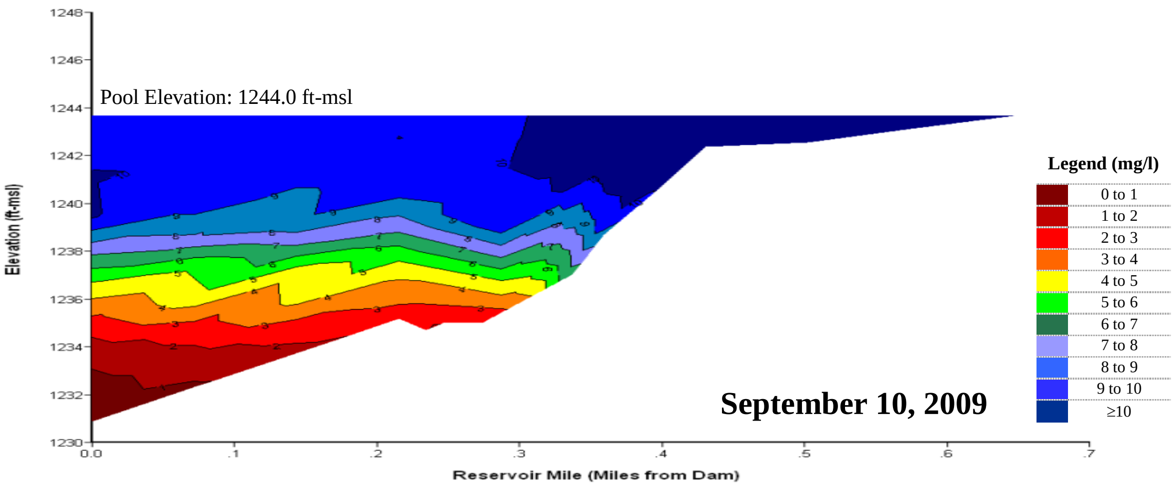


Plate 240. (Continued).

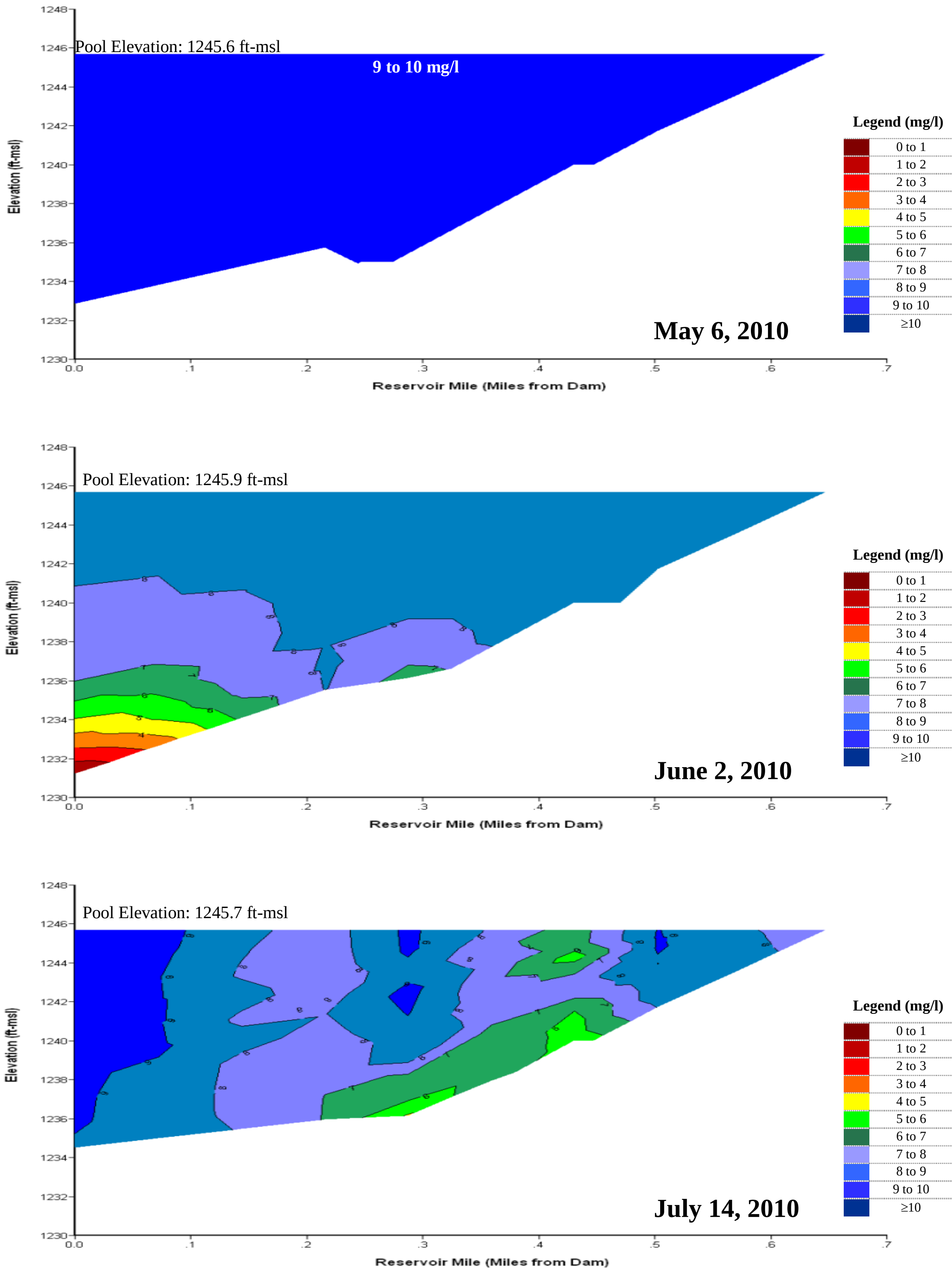
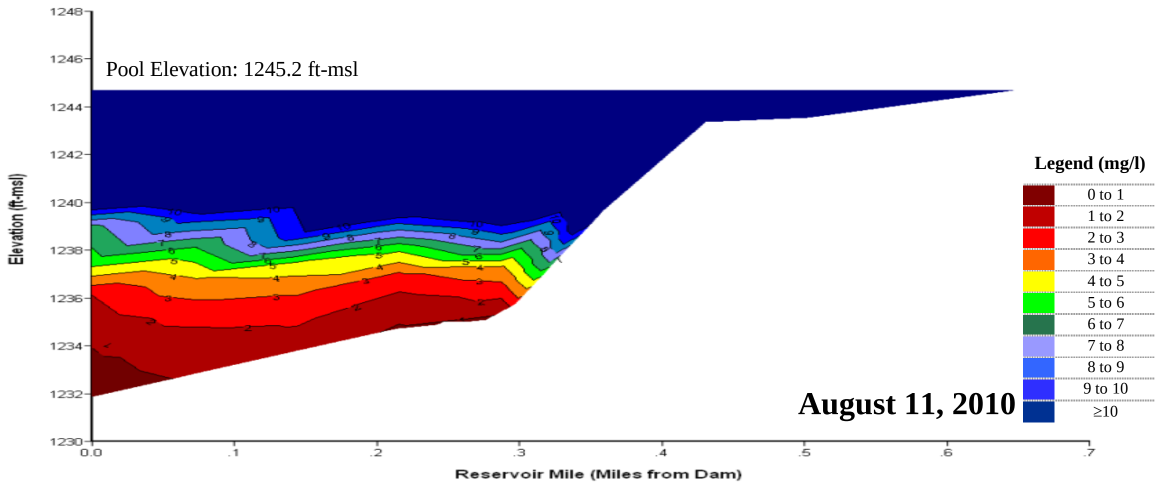


Plate 241. Longitudinal dissolved oxygen (mg/l) contour plots of Yankee Hill Reservoir based on depth-profile dissolved oxygen concentrations measured at sites YANLKND1, YANLKMLS1, and YANLKUPS1 in 2010.



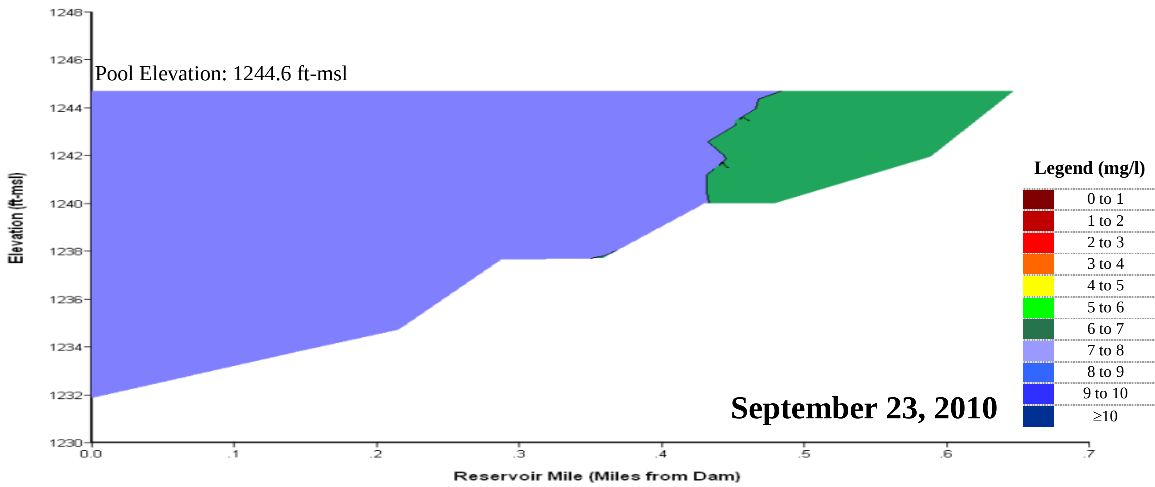


Plate 241. (Continued).

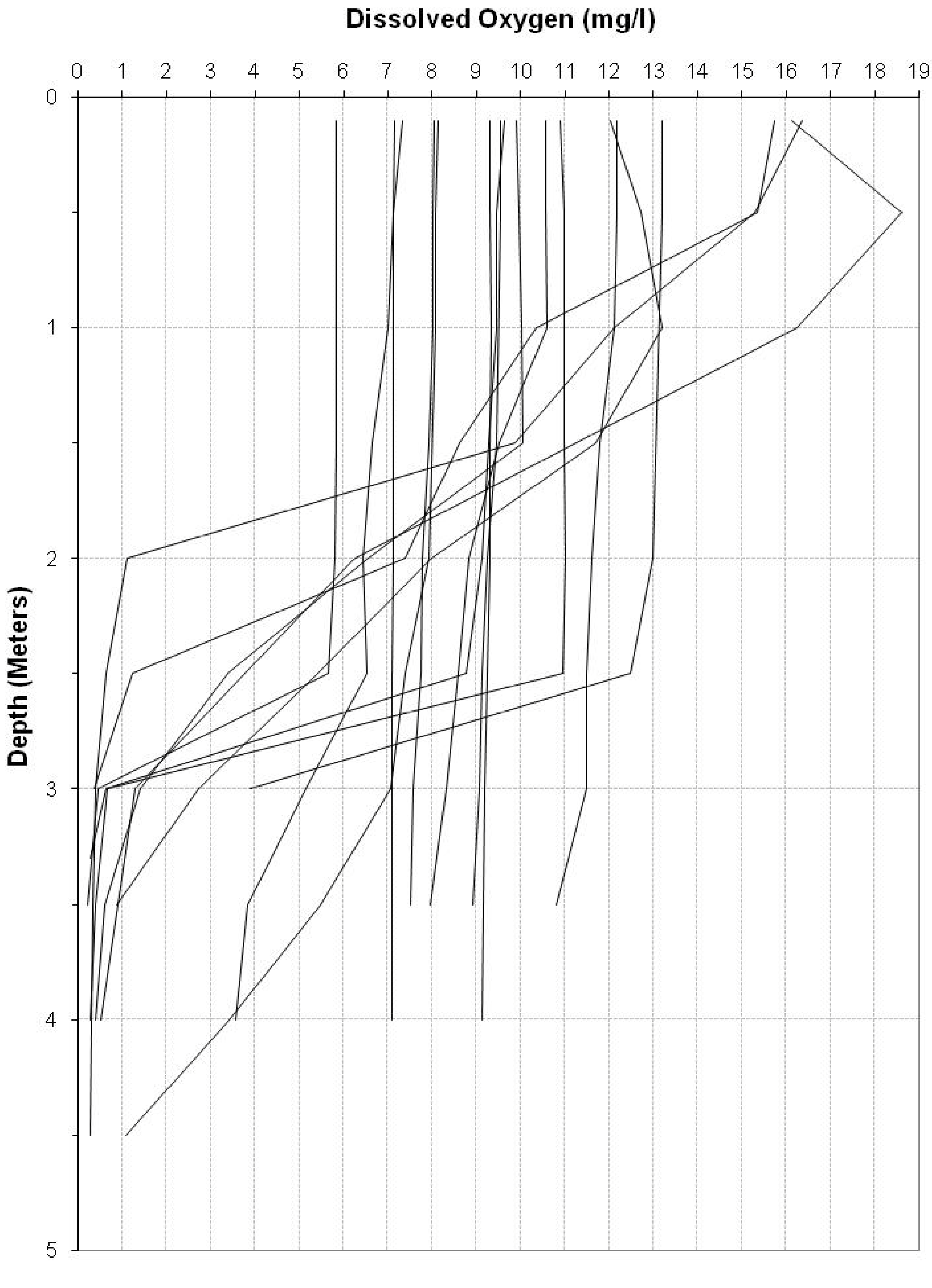


Plate 242. Dissolved oxygen depth profiles for Yankee Hill Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., YANLKND1) during the summer over the 4-year period of 2007 through 2010.

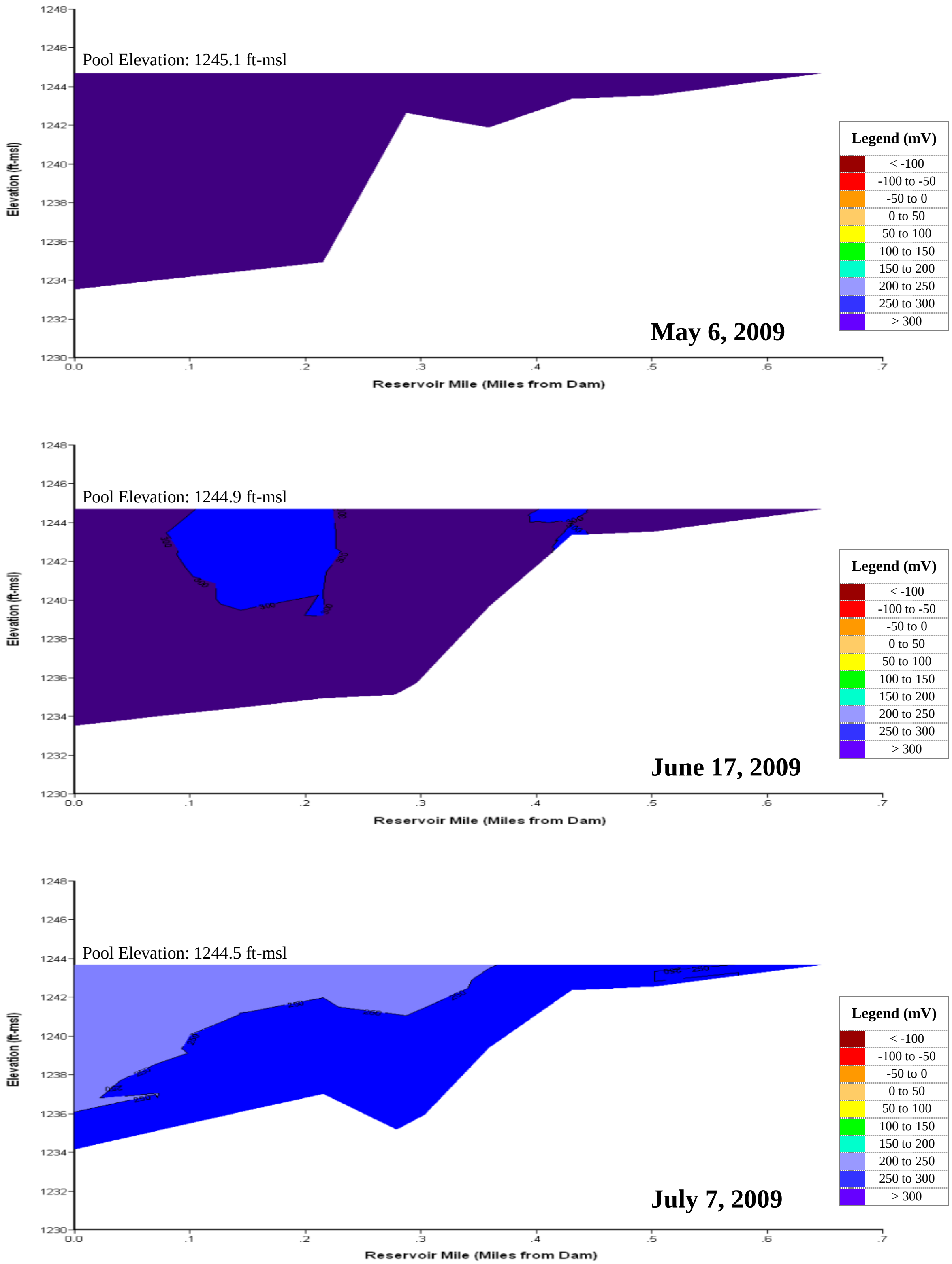
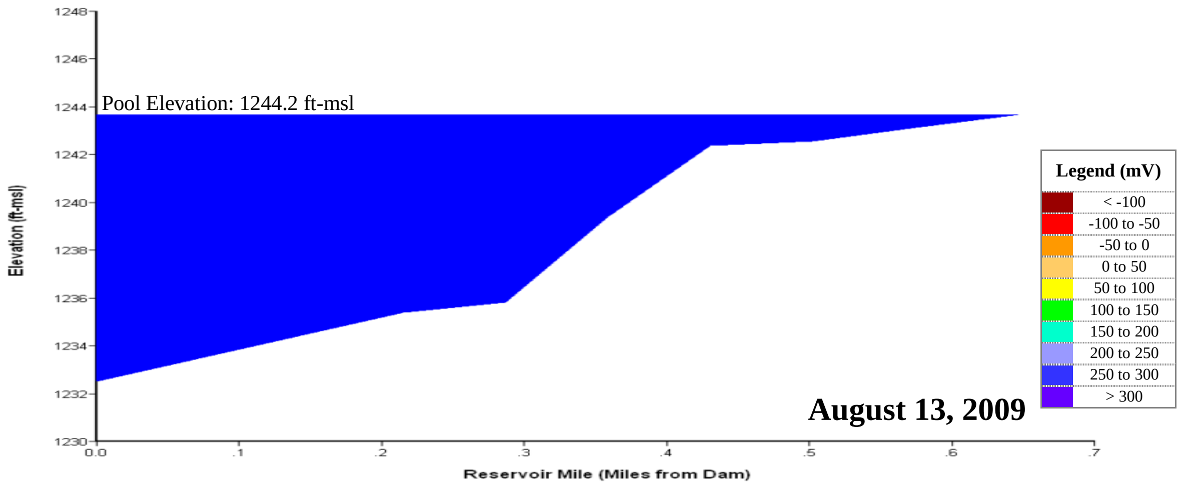


Plate 243. Longitudinal oxidation-reduction (mV) contour plots of Yankee Hill Reservoir based on depth-profile ORP levels measured at sites YANLKND1 and YANLKMLS1 in 2009.



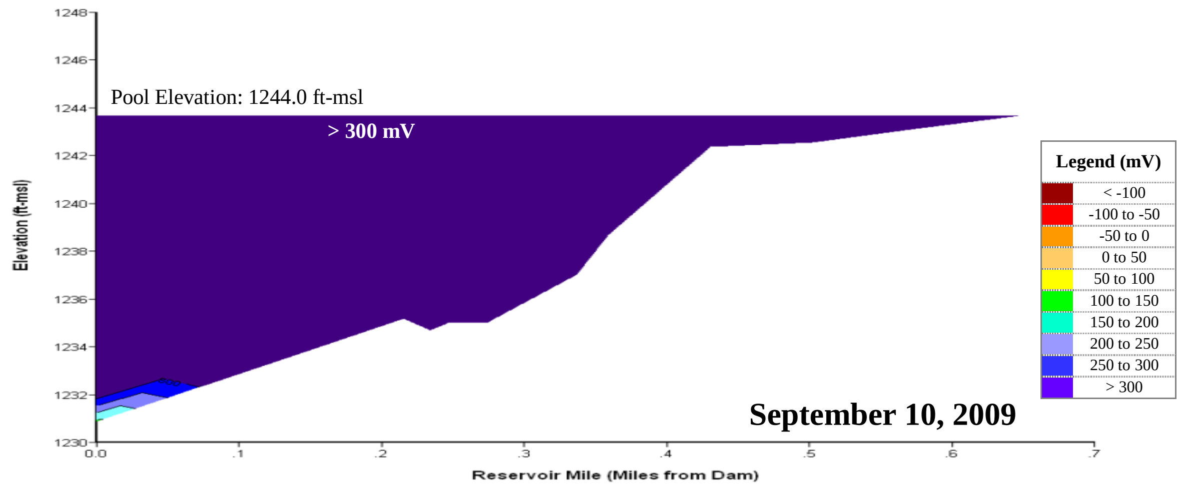
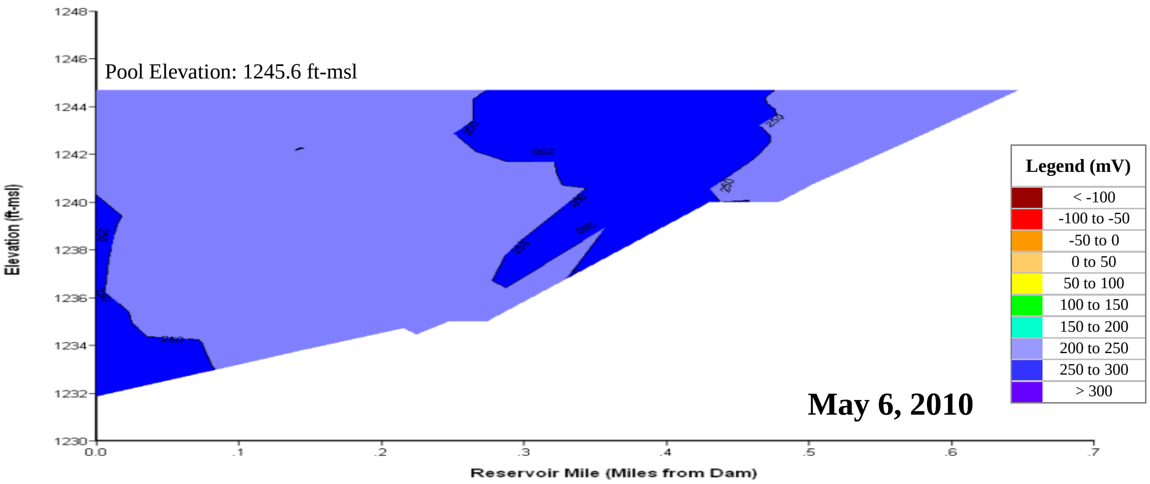
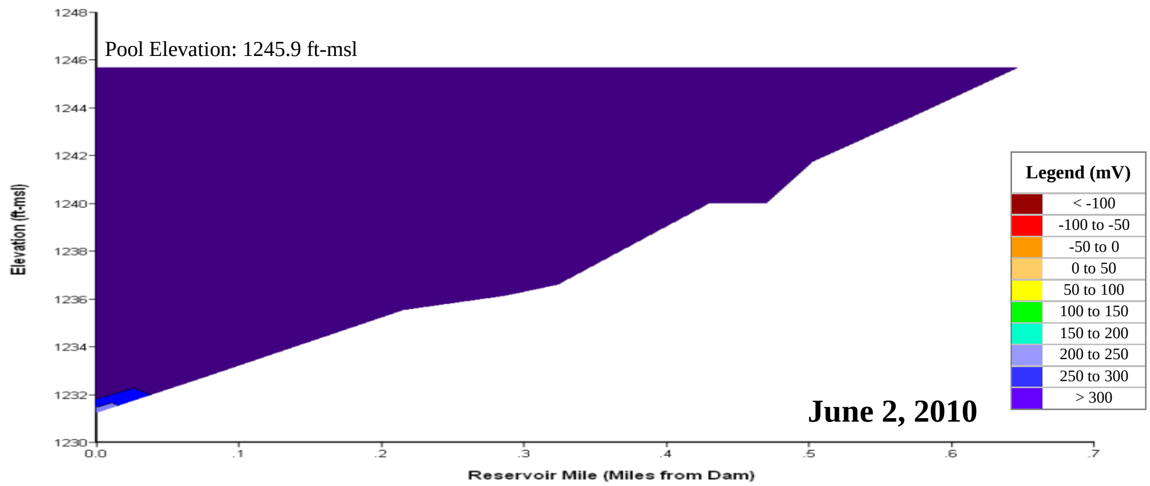


Plate 243. (Continued).





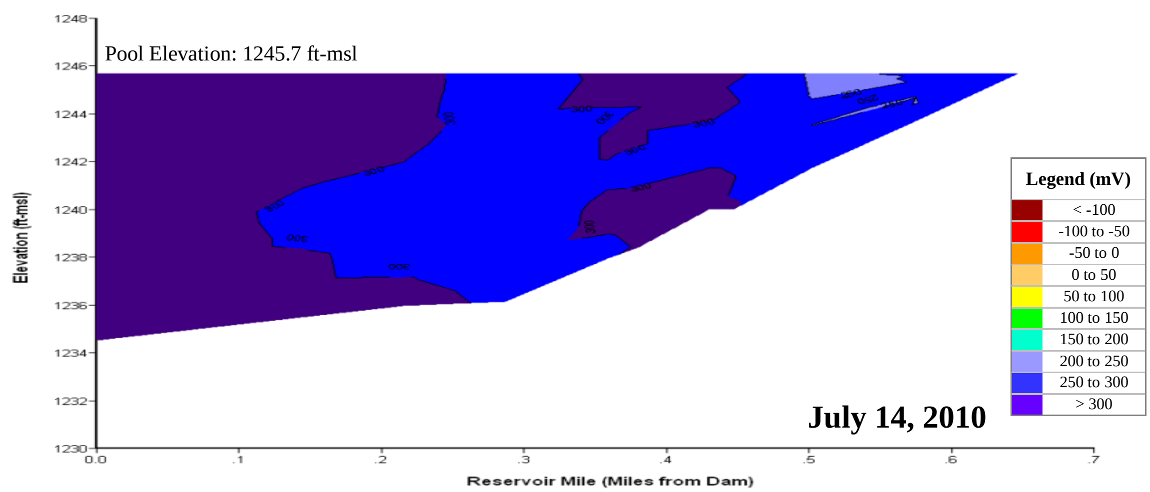
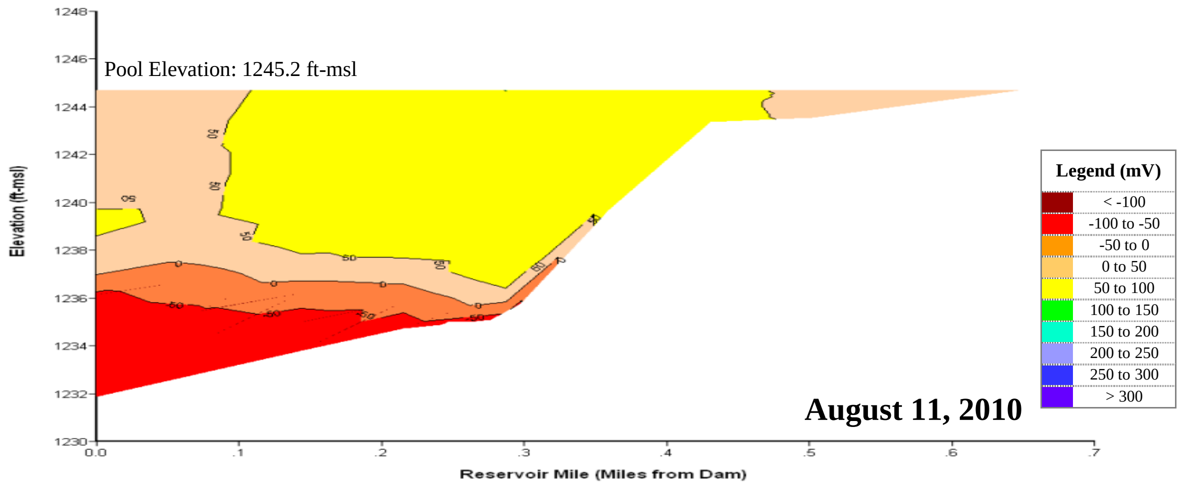


Plate 244. Longitudinal oxidation-reduction (mV) contour plots of Yankee Hill Reservoir based on depth-profile ORP levels measured at sites YANLKND1, YANLKMLS1, and YANLKUPS1 in 2010.



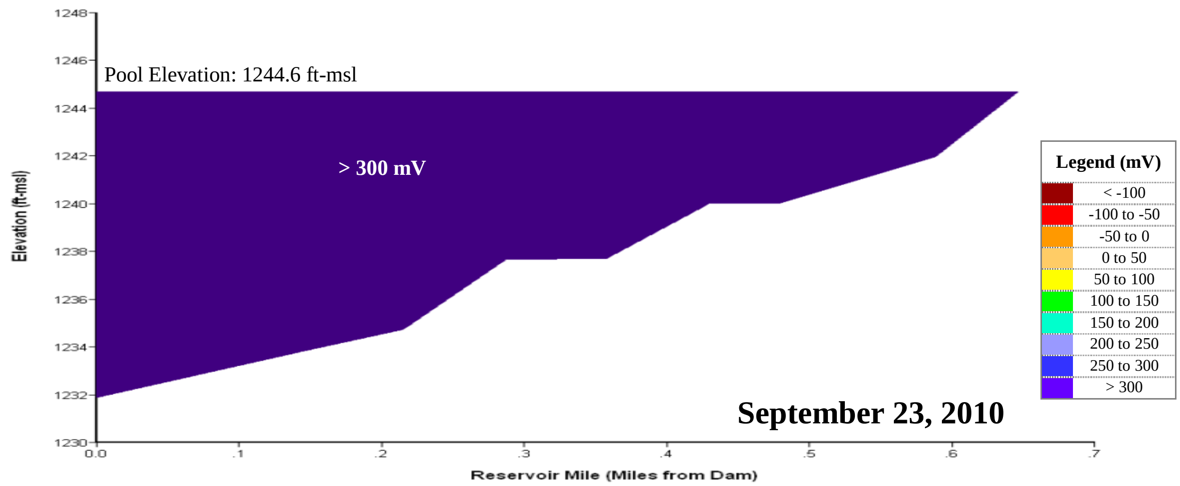


Plate 244. (Continued).

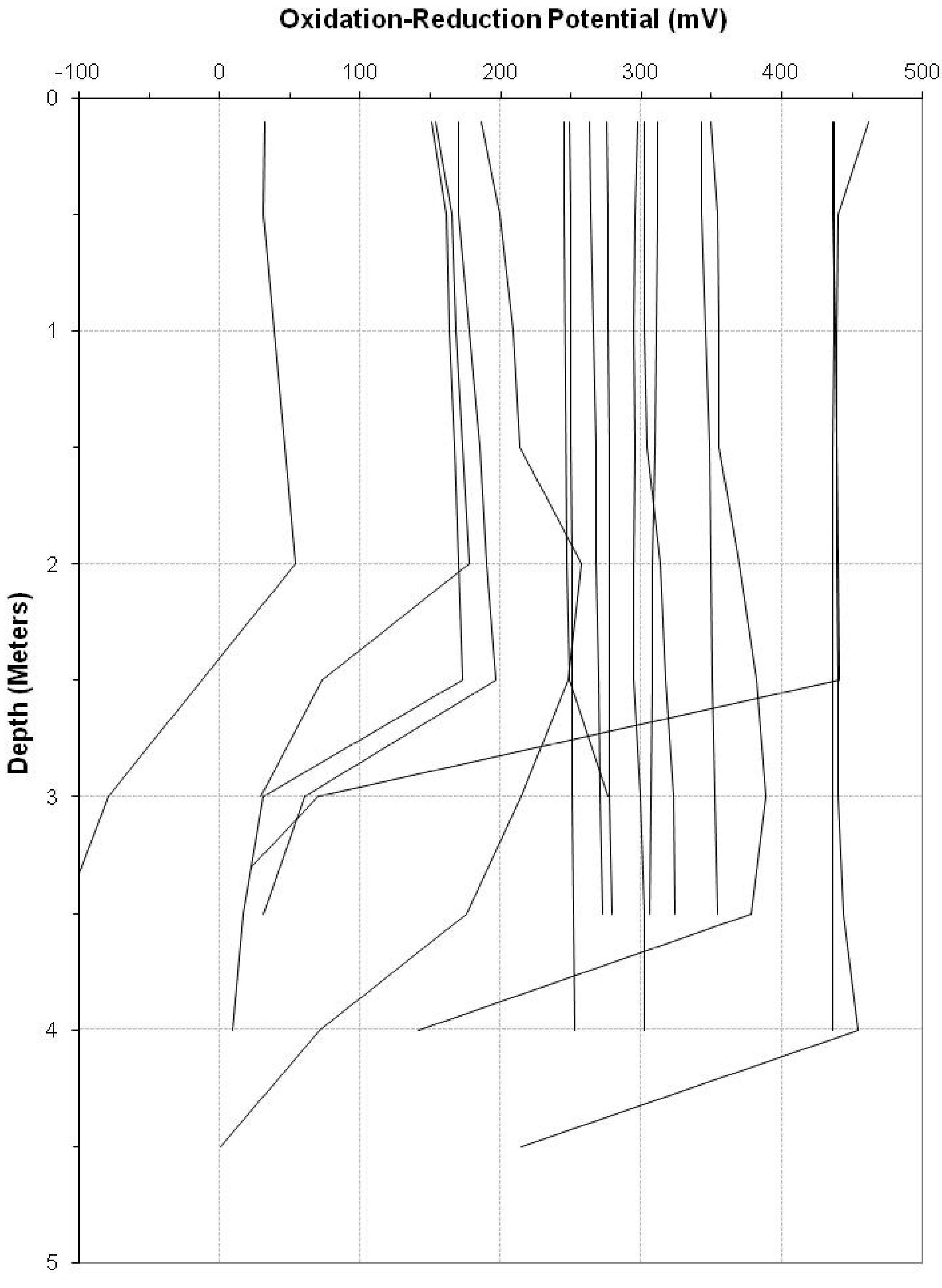
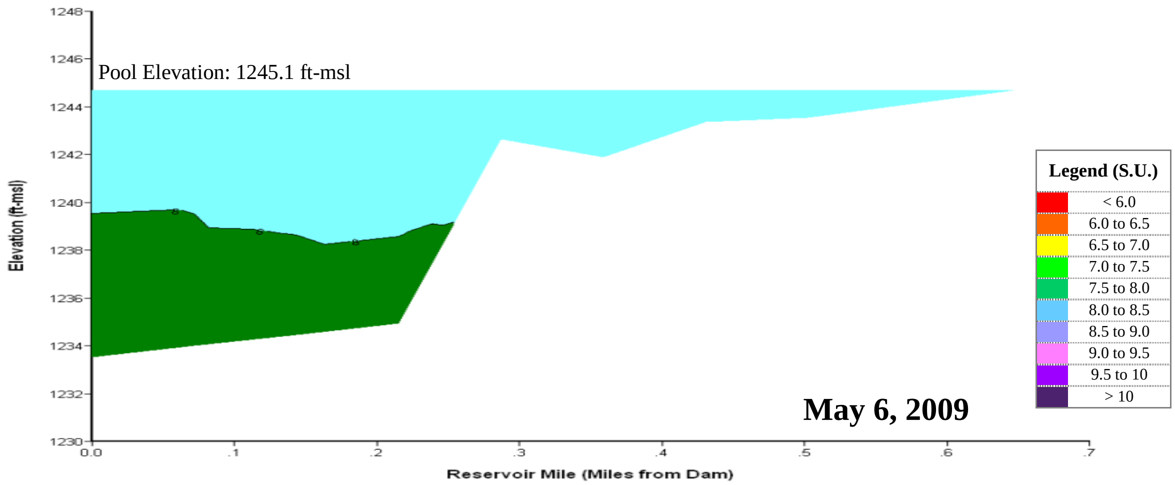
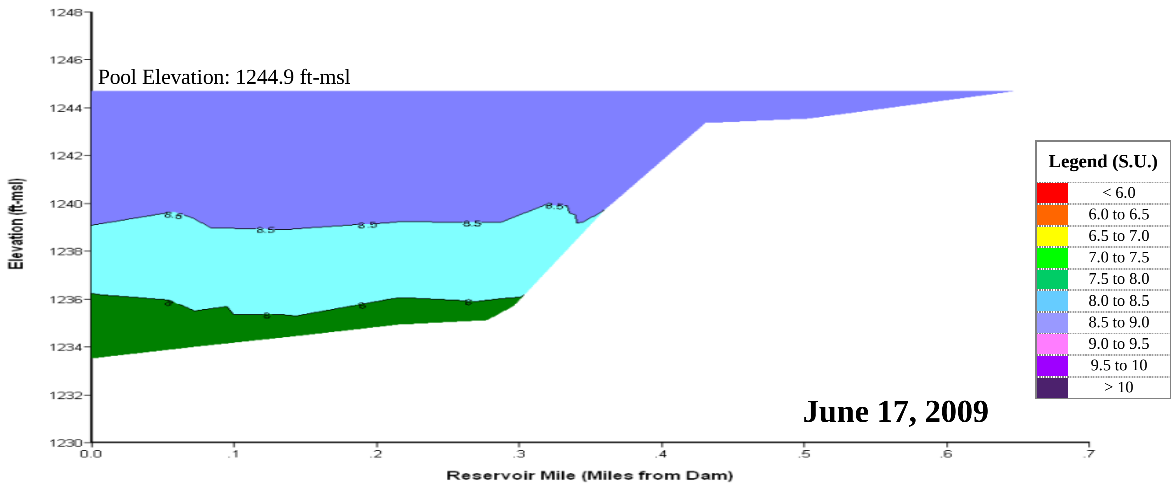


Plate 245. Oxidation-reduction depth profiles for Yankee Hill Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., YANLKND1) during the summer over the 4-year period of 2007 through 2010.





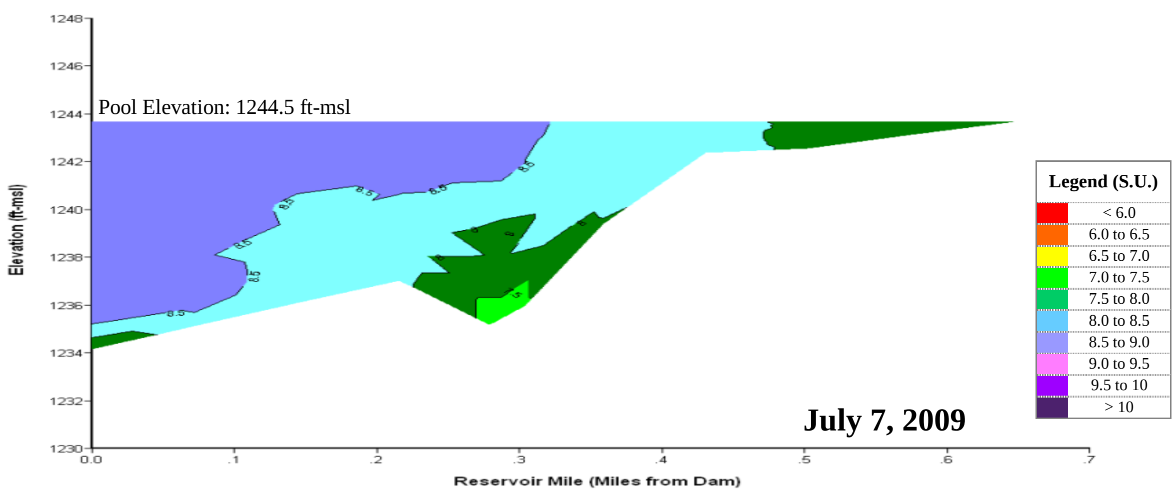
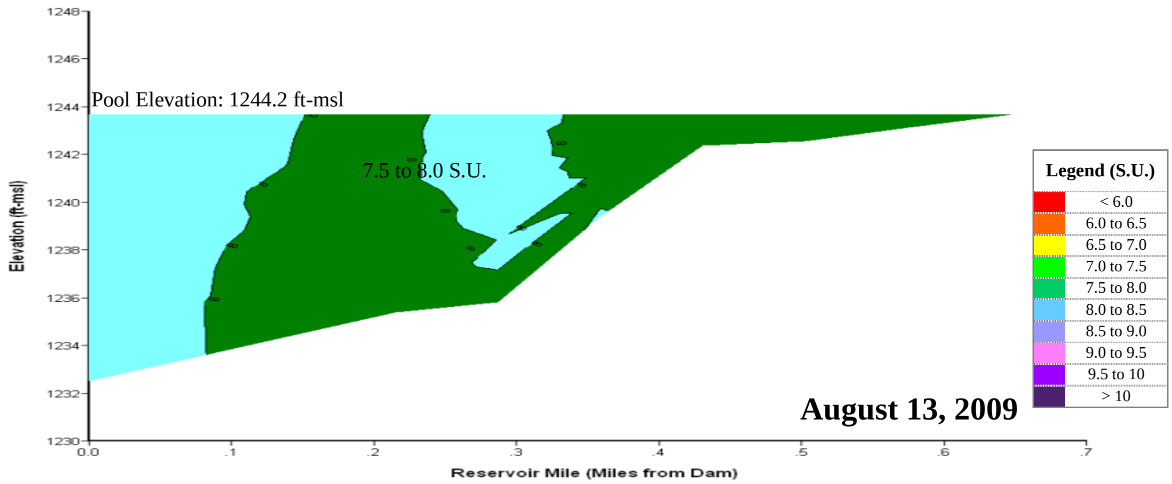


Plate 246. Longitudinal pH (S.U.) contour plots of Yankee Hill Reservoir based on depth-profile pH levels measured at sites YANLKND1 and YANLKMLS1 in 2009.



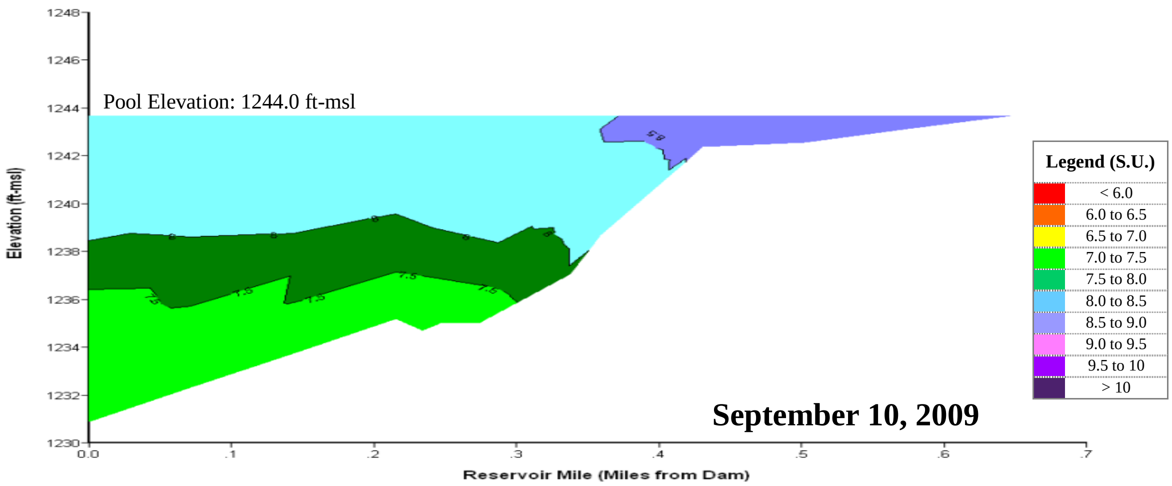
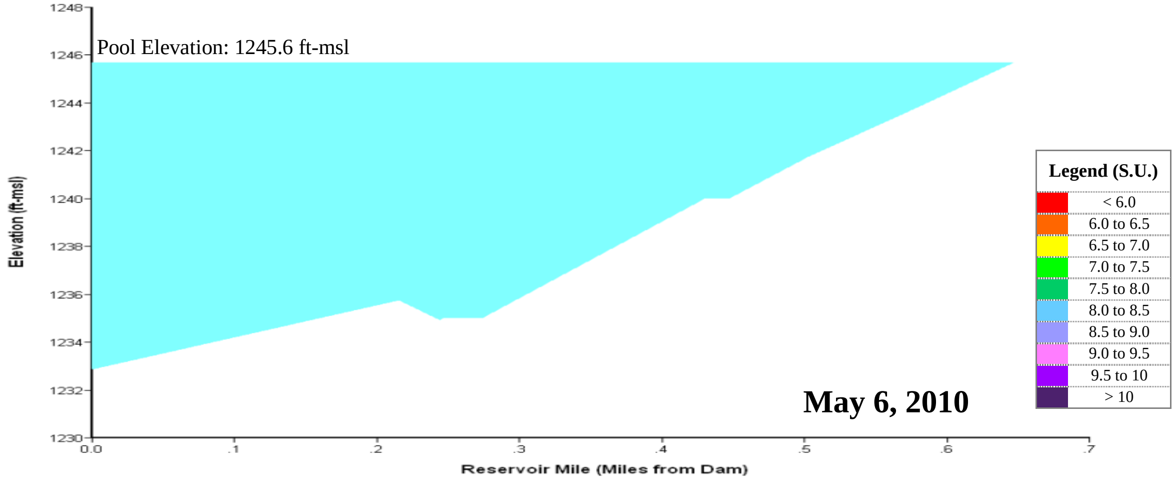
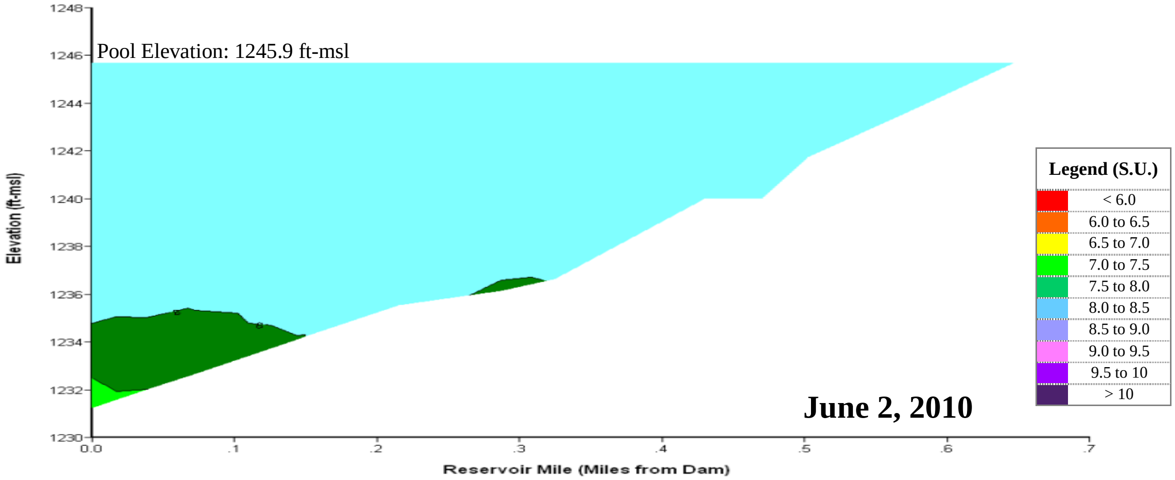


Plate 246. (Continued).





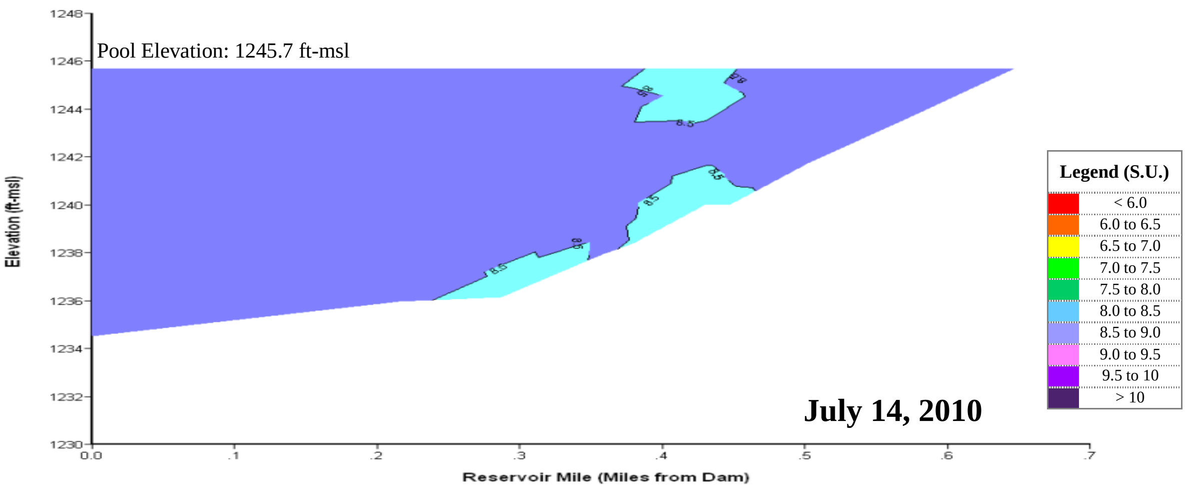
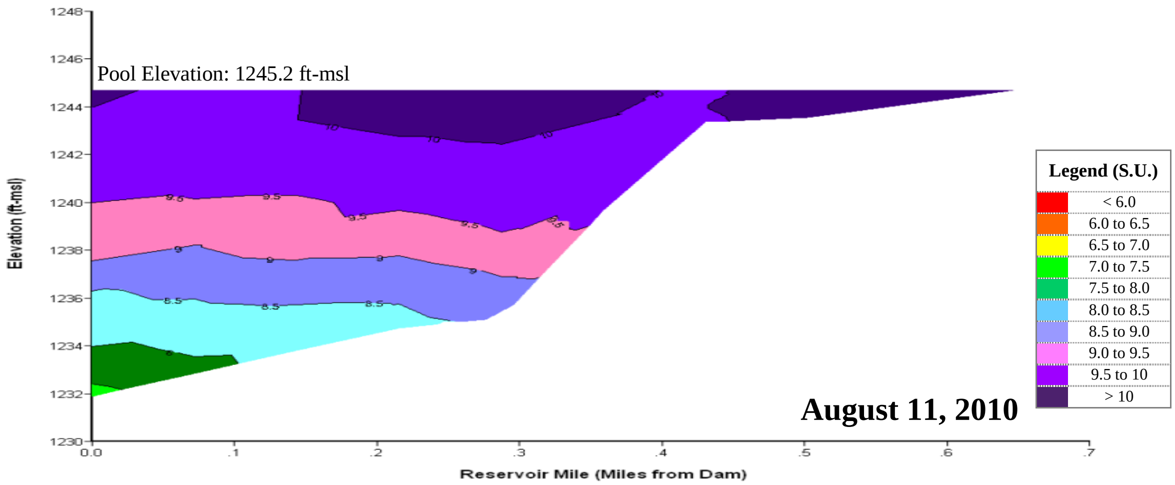


Plate 247. Longitudinal pH (S.U.) contour plots of Yankee Hill Reservoir based on depth-profile pH levels measured at sites YANLKND1, YANLKMLS1, and YANLKUPS1 in 2010.



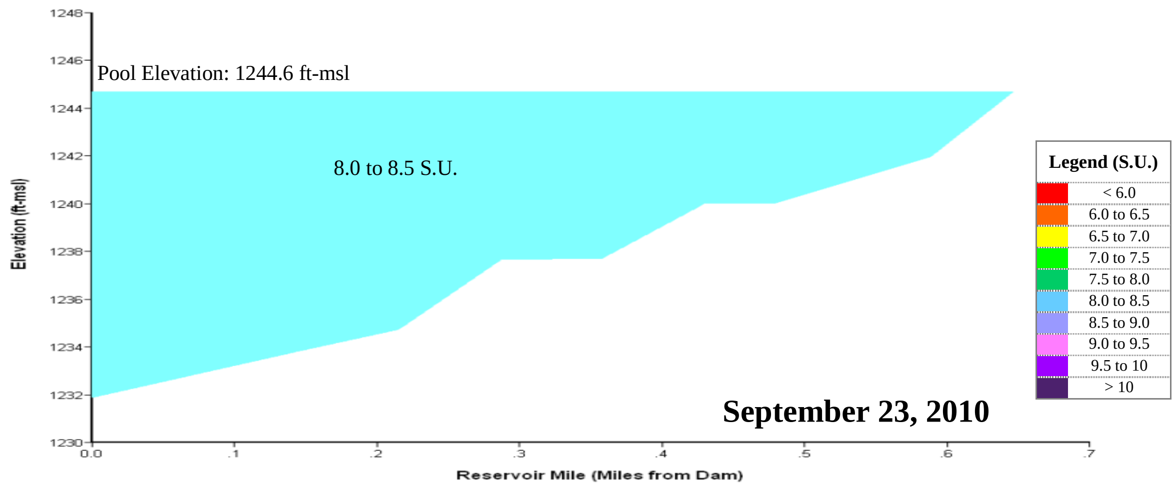


Plate 247. (Continued).

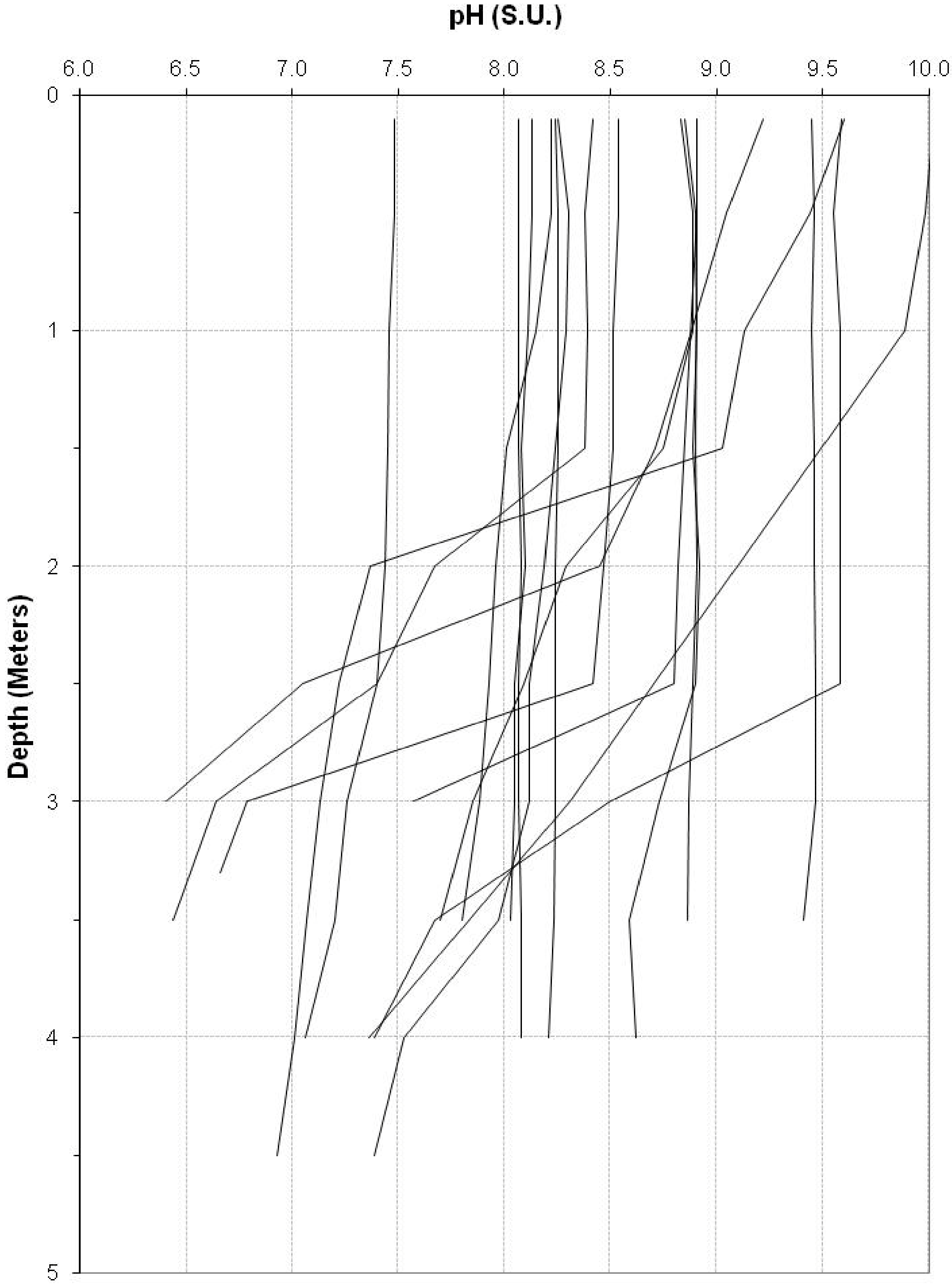


Plate 248. pH depth profiles for Yankee Hill Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., YANLKND1) during the summer over the 4-year period of 2007 through 2010.

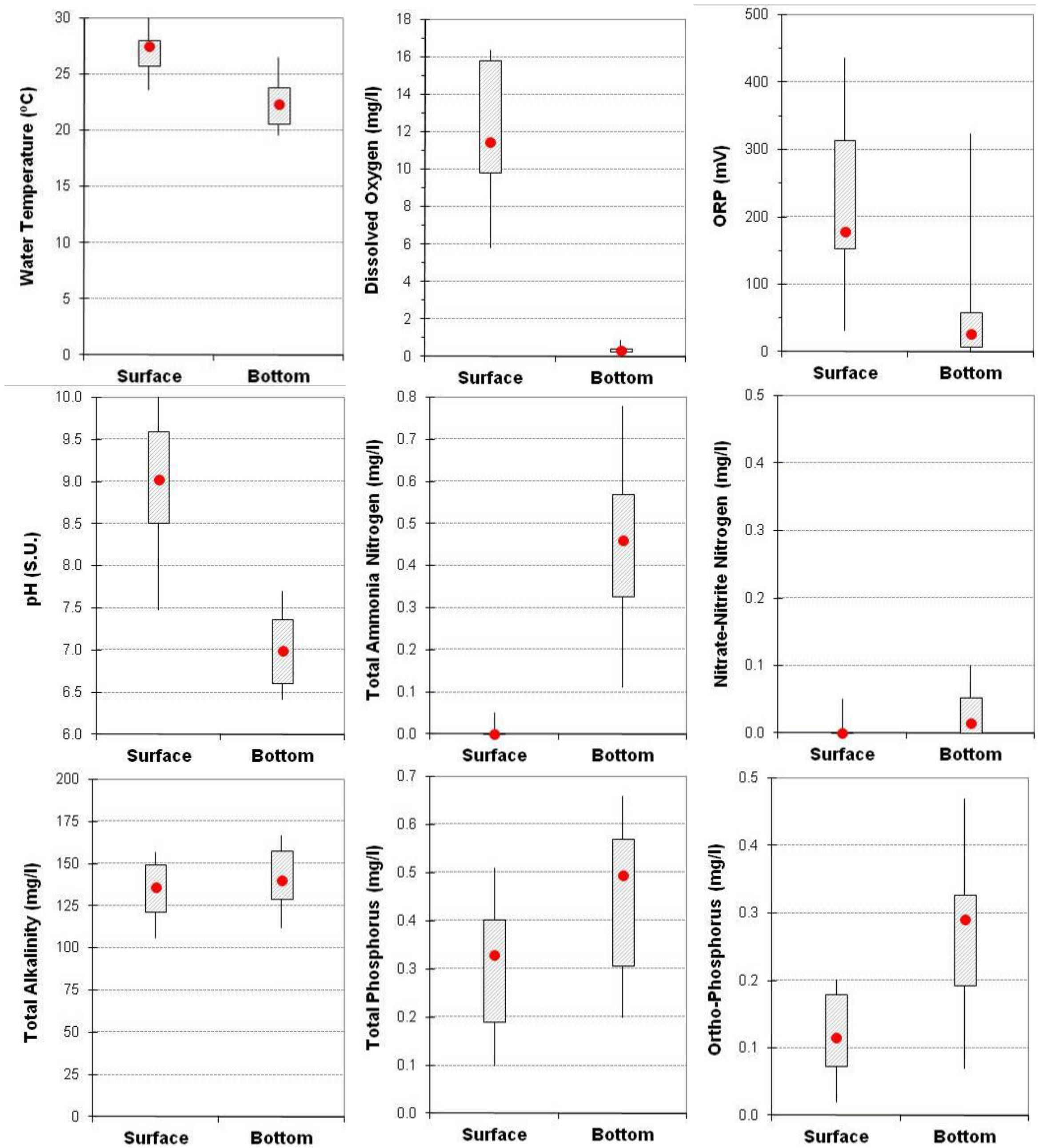


Plate 249. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, alkalinity, total ammonia nitrogen, nitrate-nitrite nitrogen, total phosphorus, and ortho-phosphorus measured in Yankee Hill Reservoir when summer hypoxic conditions were present during the 4-year period 2007 through 2010. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

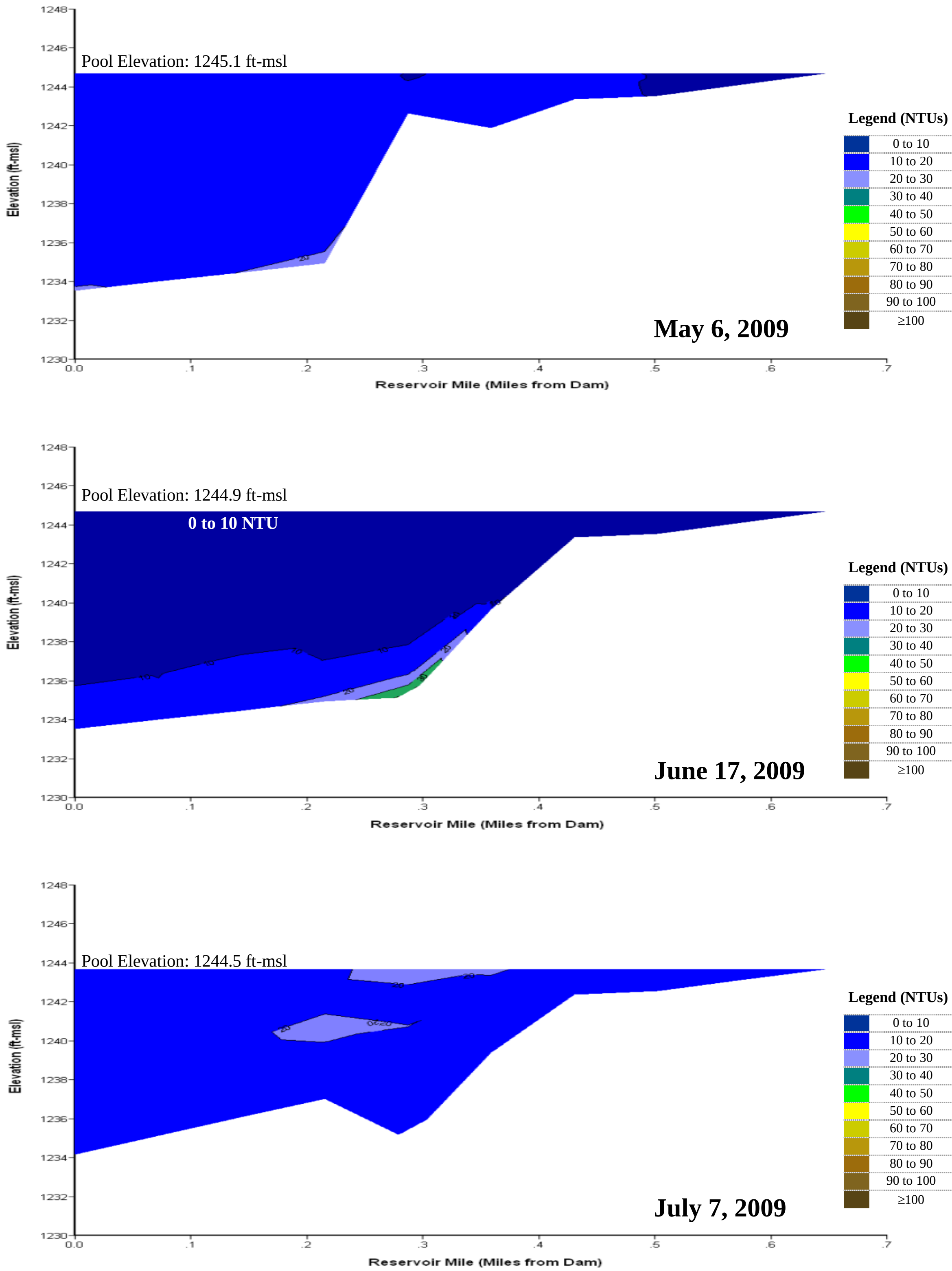
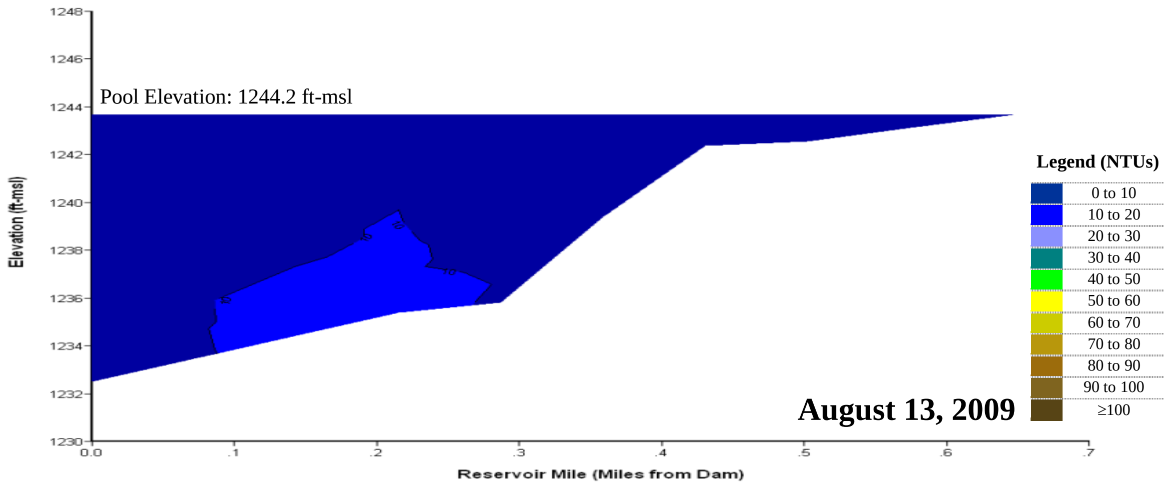


Plate 250. Longitudinal turbidity (NTU) contour plots of Yankee Hill Reservoir based on depth-profile turbidity levels measured at sites YANLKND1 and YANLKMLS1 in 2009.



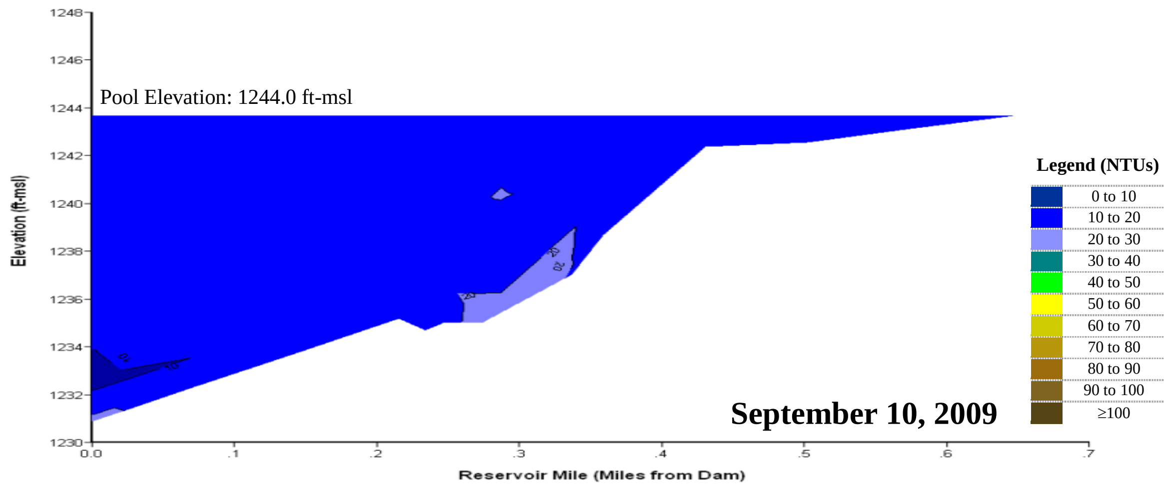
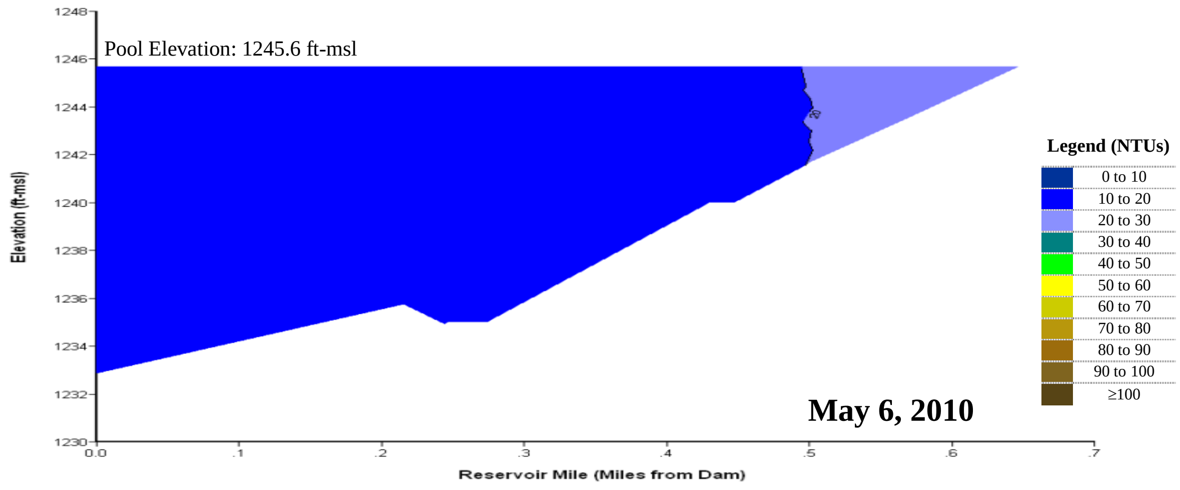
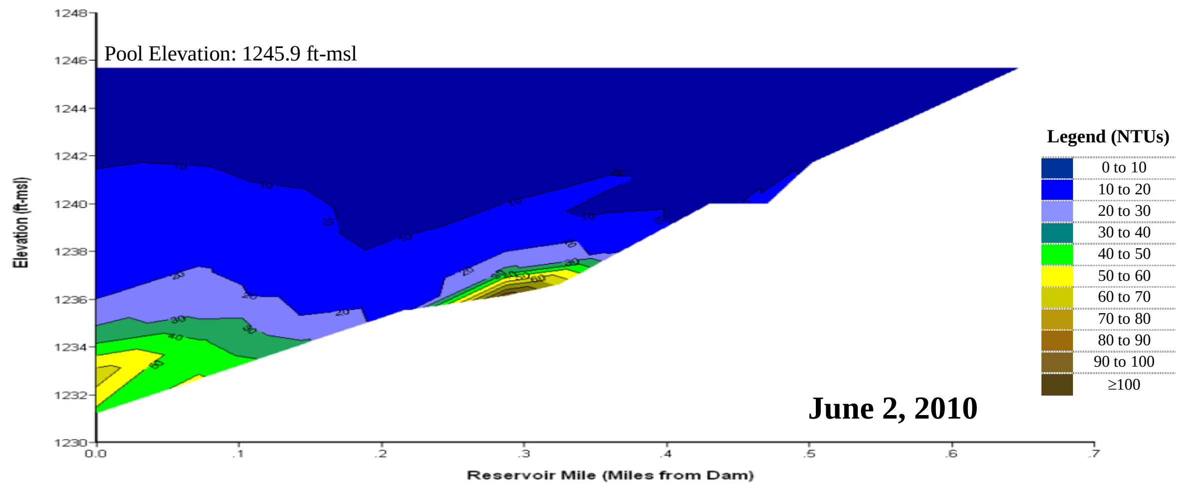


Plate 250. (Continued).





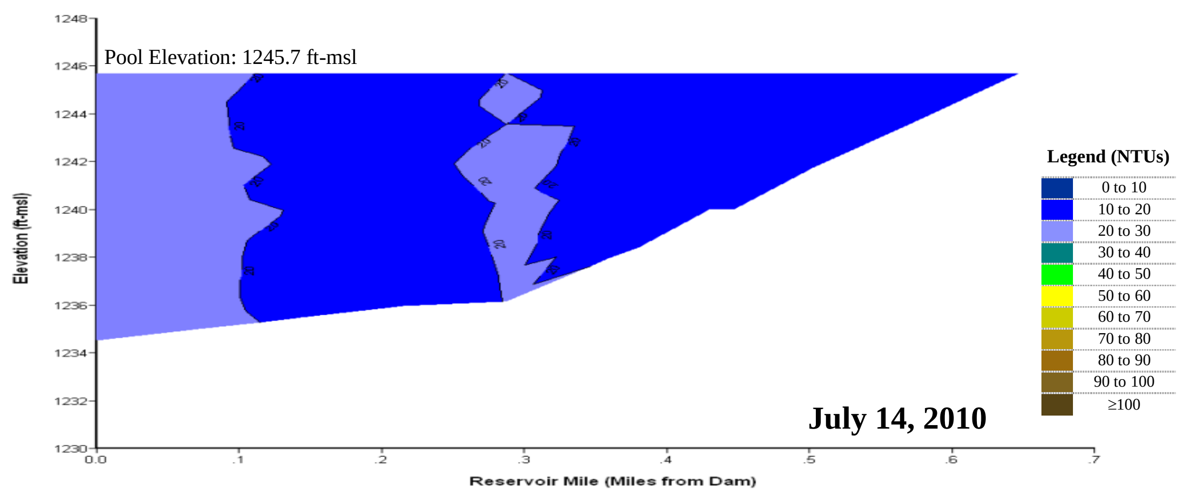
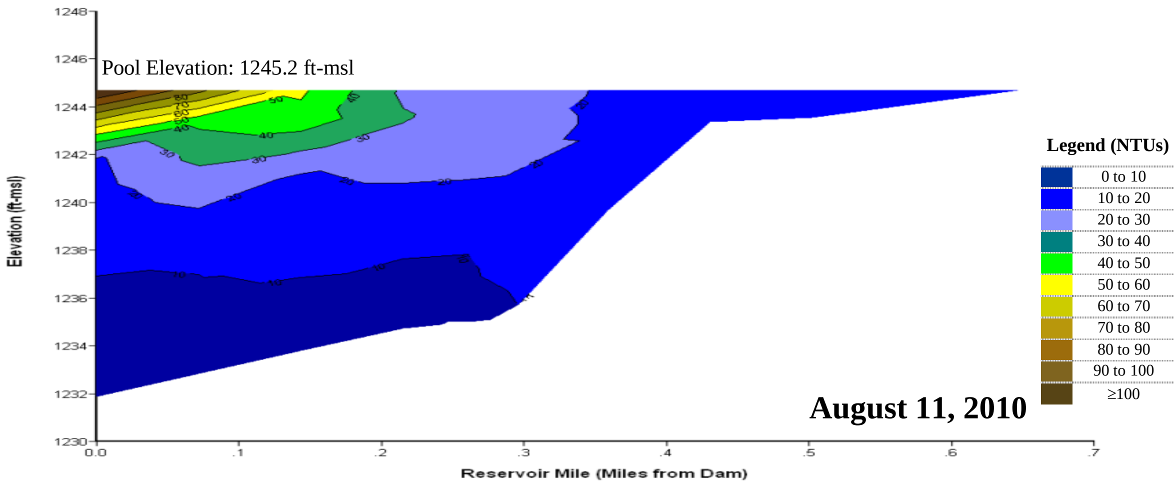


Plate 251. Longitudinal turbidity (NTU) contour plots of Yankee Hill Reservoir based on depth-profile turbidity levels measured at sites YANLKND1, YANLKMLS1, and YANLKUPS1 in 2010.



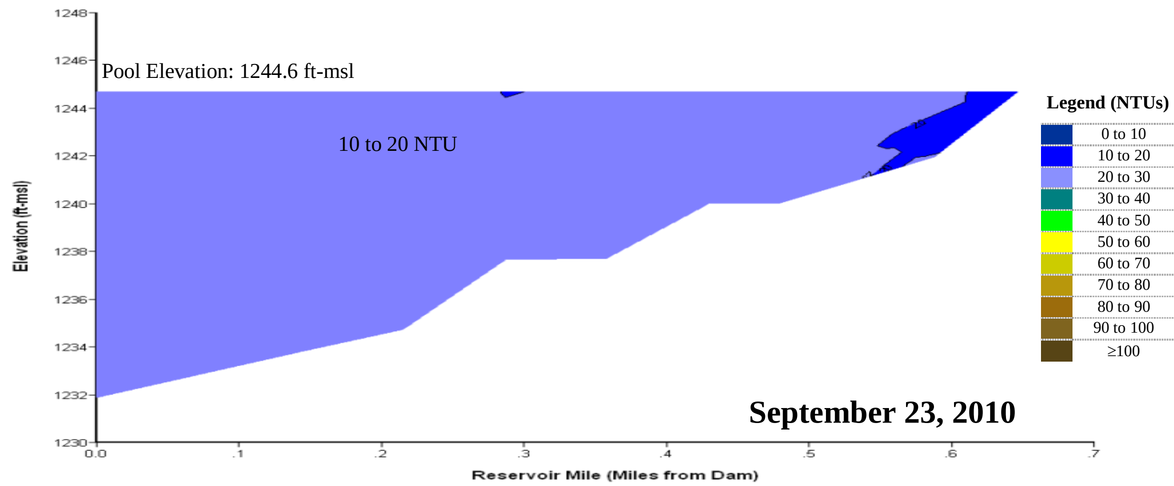


Plate 251. (Continued).

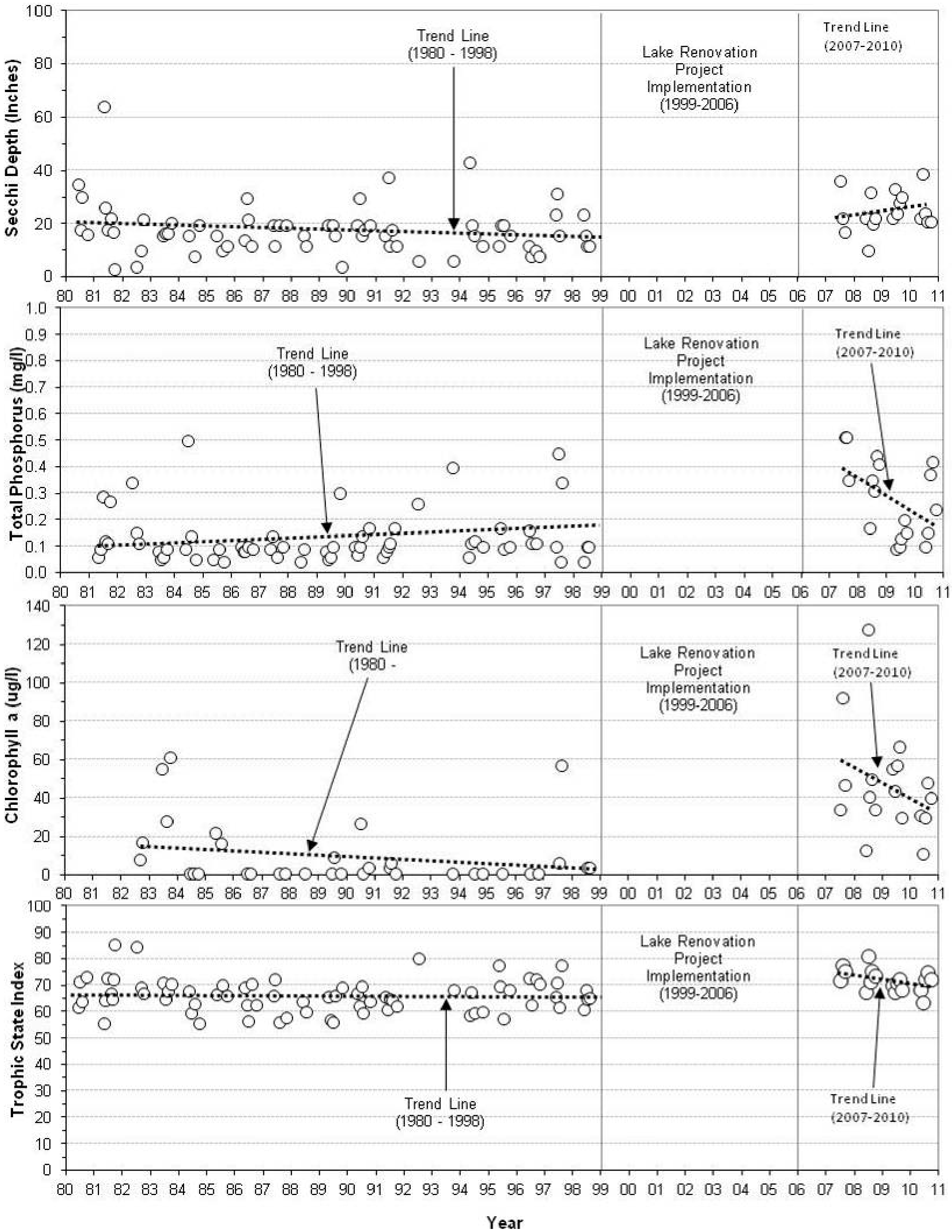


Plate 252. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Yankee Hill Reservoir at the near-dam, ambient site (i.e., site YANLKND1) over the 31-year period of 1980 through 2010.

Plate 253. Summary of runoff water quality conditions monitored in the west tributary inflow to Yankee Hill Reservoir at monitoring site YANNFWST1 during the 5-year period 2004 through 2008**.** Runoff conditions have not been monitored since 2008.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Kjeldahl N, Total (mg/l)	0.1	7	2.7	2.3	0.2	16.4	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	7	3.25	2.27	1.10	5.27	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	7	0.68	0.64	0.37	1.10	-----	-----	-----
Suspended Solids, Total (mg/l)	4	7	339	284	29	760	-----	-----	-----
Acetochlor, Total (ug/l)(C)	0.05	5	1.97	1.02	n.d.	4.50	-----	-----	-----
Alachlor, Total (ug/l)(C)	0.05	2	2.35	2.35	0.99	3.71	760(1), 76(2)	0	0%
Atrazine, Total (ug/l)(C)	0.05	7	14.16	3.08	0.23	48.30	330(1), 12(2)	3	43%
Metolachlor, Total (ug/l)(C)	0.05	7	4.43	1.06	0.42	19.91	390(1), 100(2)	0	0%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Acute criterion for aquatic life.
(2) Chronic criterion for aquatic life.
(C) Immunoassay analysis.

Plate 254. Summary of runoff water quality conditions monitored in the south tributary inflow to Yankee Hill Reservoir at monitoring site YANNFSTH1 during the 5-year period 2004 through 2008**.** Runoff conditions have not been monitored since 2008.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Kjeldahl N, Total (mg/l)	0.1	8	3.6	3.6	2.0	5.1	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	8	4.42	1.36	n.d.	26.13	-----	-----	-----
Phosphorus, Total (mg/l)	0.02	8	0.92	0.88	0.36	1.40	-----	-----	-----
Suspended Solids, Total (mg/l)	4	8	755	584	102	1,930	-----	-----	-----
Acetochlor, Total (ug/l)(C)	0.05	5	2.69	2.42	0.26	7.75	-----	-----	-----
Alachlor, Total (ug/l)(C)	0.05	2	0.28	0.28	0.13	0.43	760(1), 76(2)	0	0%
Atrazine, Total (ug/l)(C)	0.05	8	14.23	3.08	0.36	68.20	330(1), 12(2)	2	25%
Metolachlor, Total (ug/l)(C)	0.05	8	2.82	1.43	n.d.	14.52	390(1), 100(2)	0	0%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.
(B) (1) Acute criterion for aquatic life.
(2) Chronic criterion for aquatic life.
(C) Immunoassay analysis.

Plate 255. Summary of water quality conditions monitored in Bowman-Haley Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site BOWLKND1) from May to September of 2001 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at ½ the measured Secchi depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	15	2752.0	2751.9	2749.7	2753.6	-----	-----	-----
Water Temperature (°C)	0.1	315	17.5	17.6	6.4	28.0	29.4	0	0%
Dissolved Oxygen (mg/l)	0.1	311	7.8	7.7	3.3	14.8	≥ 5	17	5%
Dissolved Oxygen (% Sat.)	0.1	312	84.9	85.6	39.0	188.5	-----	-----	-----
Specific Conductance (umho/cm)	1	315	2142	2167	1204	3041	-----	-----	-----
pH (S.U.)	0.1	281	8.7	8.7	7.9	9.2	≥7.0 & ≤9.0	35	12%
Turbidity (NTUs)	1	152	19	16	4	114	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	152	291	309	82	379	-----	-----	-----
Secchi Depth (in.)	1	21	34	30	8	84	-----	-----	-----
Alkalinity, Total (mg/l)	7	44	304	309	208	396	-----	-----	-----
Ammonia, Total (mg/l)	0.02	34	0.28	0.23	0.00	0.86	2.42 [1,2], 0.63 [1,3]	0, 4	0%, 12%
Carbon, Total Organic (mg/l)	0.05	30	13.59	14.00	9.30	16.00	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	137	-----	3	n.d.	19	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab Determined	1	12	-----	5	n.d.	71	-----	-----	-----
Hardness, Total (mg/l)	0.4	16	320.6	316.5	249.0	391.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	44	1.3	1.1	0.5	3.8	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	43	-----	0.08	n.d.	0.34	1.0	0	0%
Phosphorus, Total (mg/l)	0.1	44	0.1	0.1	n.d.	0.2	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	42	-----	0.02	n.d.	0.11	-----	-----	-----
Sulfate, Total (mg/l)	1	13	621	634	506	708	250	13	100%*
Suspended Solids, Total (mg/l)	4	44	15	14	n.d.	40	-----	-----	-----
Arsenic, Total (ug/l)	1	4	-----	n.d.	n.d.	4	340[2], 150[3]	0	0%
Beryllium, Dissolved (ug/l)	2	3	-----	n.d.	n.d.	n.d.	4[4]	0	0%
Cadmium, Dissolved (ug/l)	0.2	3	-----	0.2	n.d.	6.0	16.6[2], 6.1[3]	0	0%
Chromium, Dissolved (ug/l)	10	3	-----	n.d.	n.d.	10	4633 [2], 221 [3]	0	0%
Copper, Total (ug/l)	2	4	-----	n.d.	n.d.	2	42[2], 25[3]	1, 1	8%, 8%
Lead, Total (ug/l)	0.5	4	-----	n.d.	n.d.	n.d.	354[2], 14[3]	0	0%
Mercury, Total (ug/l)	0.02	4	-----	0.02	n.d.	0.02	1.7[2], 0.012[3], 0.05[4]	0, 3, 0	0%, 75%, 0%
Zinc, Total (ug/l)	3	4	10.30	8.80	7.60	16.00	318[2,3]	0	0%
Alachlor, Total (ug/l)[C]	0.05	9	-----	n.d.	n.d.	n.d.	2[4]	0	0%
Atrazine, Total (ug/l)[C]	0.05	9	-----	n.d.	n.d.	0.07	3[4]	0	0%
Metolachlor, Total (ug/l)[C]	0.05	9	-----	n.d.	n.d.	0.10	40[4]	0	0%
Pesticide Scan (ug/l)[D]	0.13	5	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.
(2) Acute criterion for aquatic life.
(3) Chronic criterion for aquatic life.
Note: North Dakota's chronic WQS criterion for Mercury was below the detection limit during the reporting period.
(4) Human health criterion for surface waters.
Note: North Dakota's WQS criteria for metals are based on total recoverable, some analyzed metal concentrations were dissolved. Listed criteria are given for comparison and were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, atrazine, benfluralin, butylate, chlorpyrifos, cyanazine, cycloate, EPTC, hexazinone, isopropalin, metribuzin, metolachlor, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, profluralin, prometon, propachlor, propazine, simazine, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted percent exceedence indicates use impairment based on State of North Dakota's 2010 Section 303(d) impairment assessment criteria.

Plate 256. Summary of water quality conditions monitored in Bowman-Haley Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site BOWLKMLN1) from May to September during 2003 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean*	Median	Min.	Max.	State WQS Criteria	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	14	2751.9	2751.9	2749.7	2753.7	-----	-----	-----
Water Temperature (°C)	0.1	157	18.3	18.2	11.5	25.5	29.4	0	0%
Dissolved Oxygen (mg/l)	0.1	157	7.9	7.9	2.4	12.5	≥ 5	9	6%
Dissolved Oxygen (% Sat.)	0.1	157	88.2	87.3	27.5	144.5	-----	-----	-----
Specific Conductance (umho/cm)	1	157	2232	2134	1447	3038	-----	-----	-----
pH (S.U.)	0.1	157	8.6	8.6	7.9	9.1	≥7.0 & ≤9.0	13	8%
Turbidity (NTUs)	1	101	21	19	3	94	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	104	306	338	95	409	-----	-----	-----
Secchi Depth (in.)	1	14	37	32	14	84	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	93	-----	3	0	21	-----	-----	-----

* Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

Plate 257. Summary of water quality conditions monitored in Bowman-Haley Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site BOWLKMLS1) from May to September during 2003 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean*	Median	Min.	Max.	State WQS Criteria	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	14	2751.9	2751.9	2749.7	2753.6	-----	-----	-----
Water Temperature (°C)	0.1	98	18.0	17.7	11.0	25.8	29.4	0	0%
Dissolved Oxygen (mg/l)	0.1	98	8.0	7.9	5.5	11.5	≥ 5	0	0%
Dissolved Oxygen (% Sat.)	0.1	98	89.5	86.8	63.5	156.5	-----	-----	-----
Specific Conductance (umho/cm)	1	98	2209	1978	1426	3065	-----	-----	-----
pH (S.U.)	0.1	98	8.6	8.7	8.0	9.1	≥7.0 & ≤9.0	9	9%
Turbidity (NTUs)	1	68	32	19	7	425	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	68	315	345	105	417	-----	-----	-----
Secchi Depth (in.)	1	14	27	27	12	46	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	64	5	4	0	40	-----	-----	-----

* Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

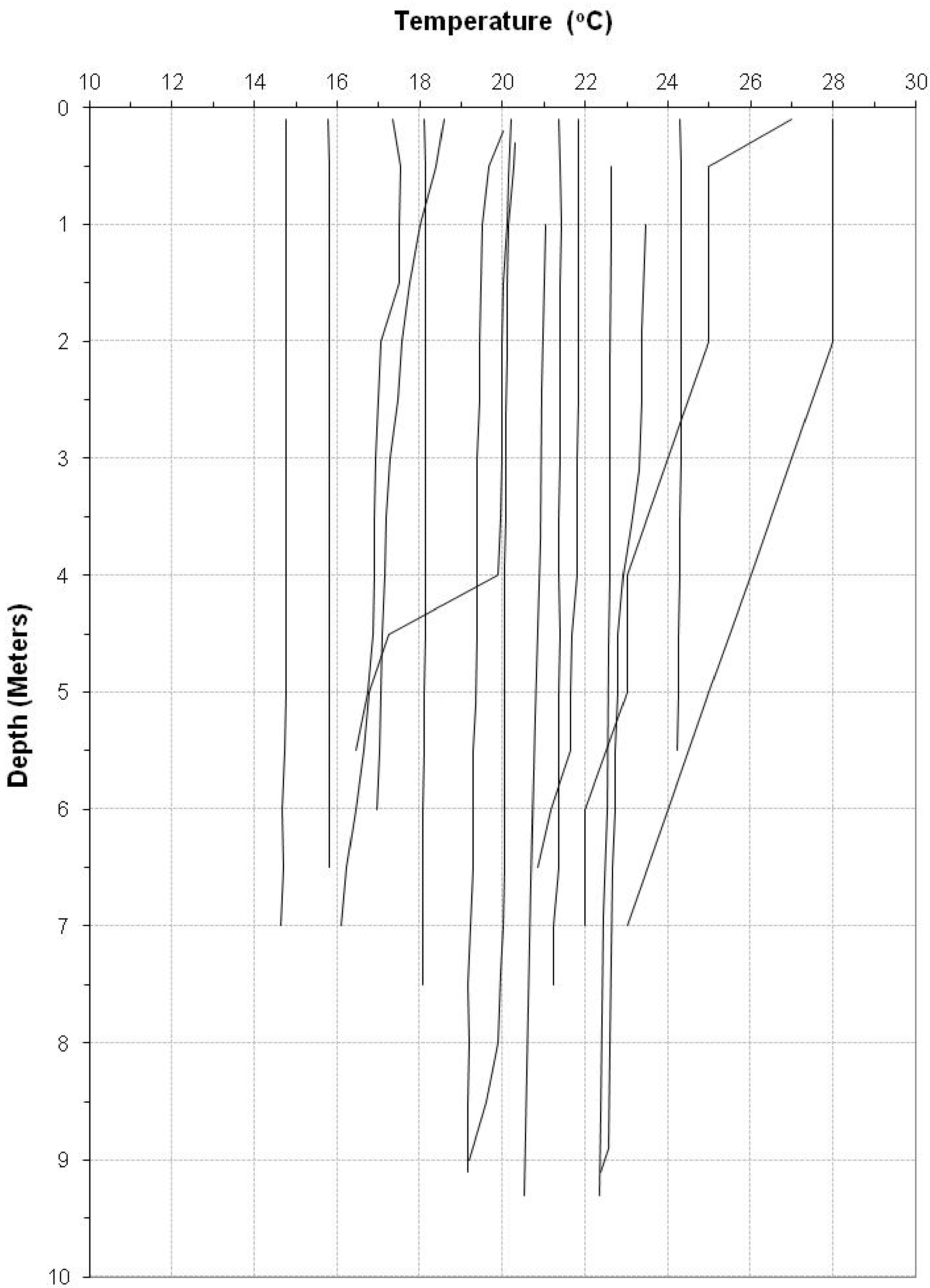


Plate 258. Temperature depth profiles for Bowman-Haley Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., BOWLKND1) during the summer over the 10-year period 2001 through 2010.

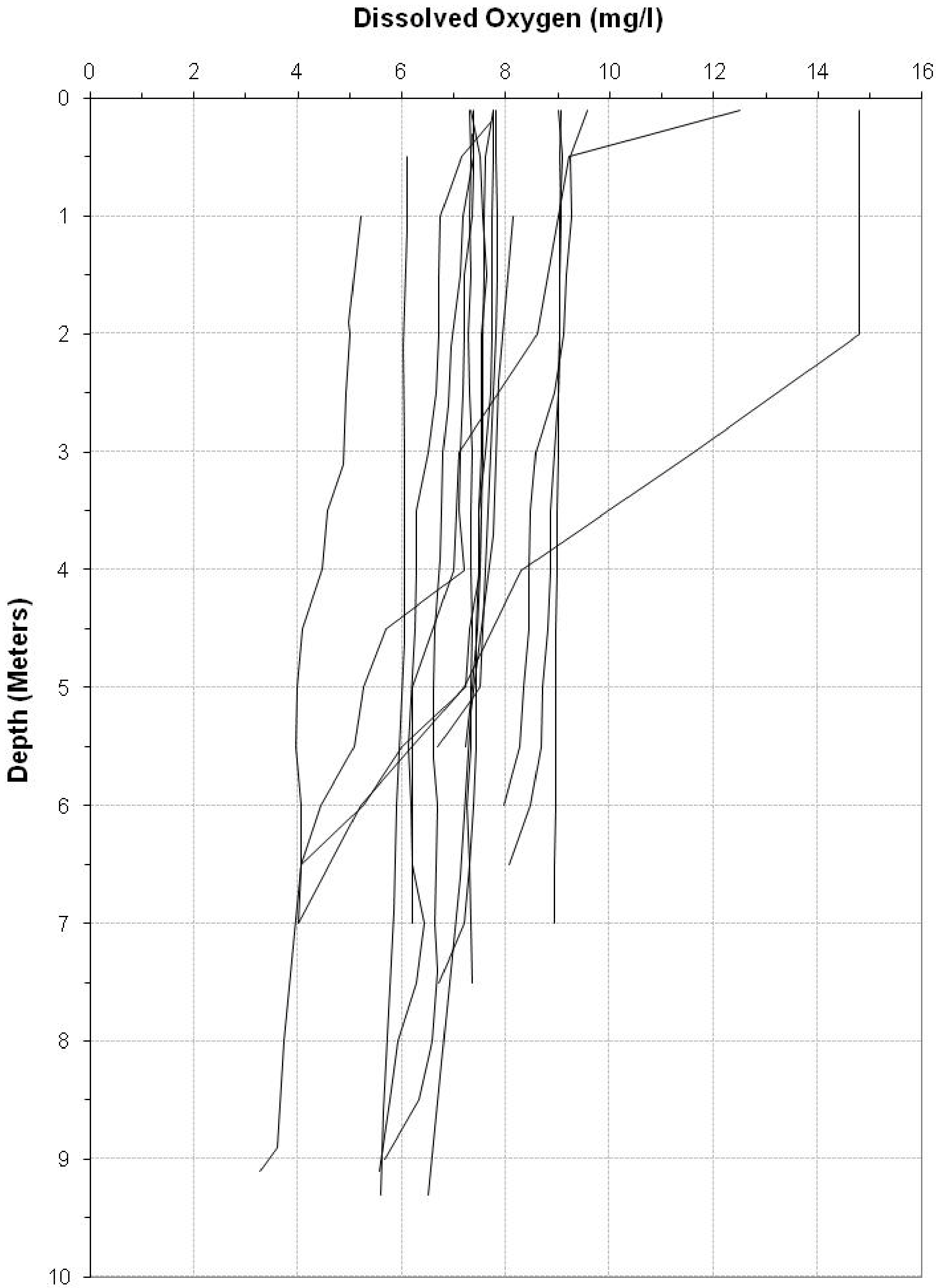


Plate 259. Dissolved Oxygen depth profiles for Bowman-Haley Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., BOWLKND1) during the summer over the 10-year period 2001 through 2010.

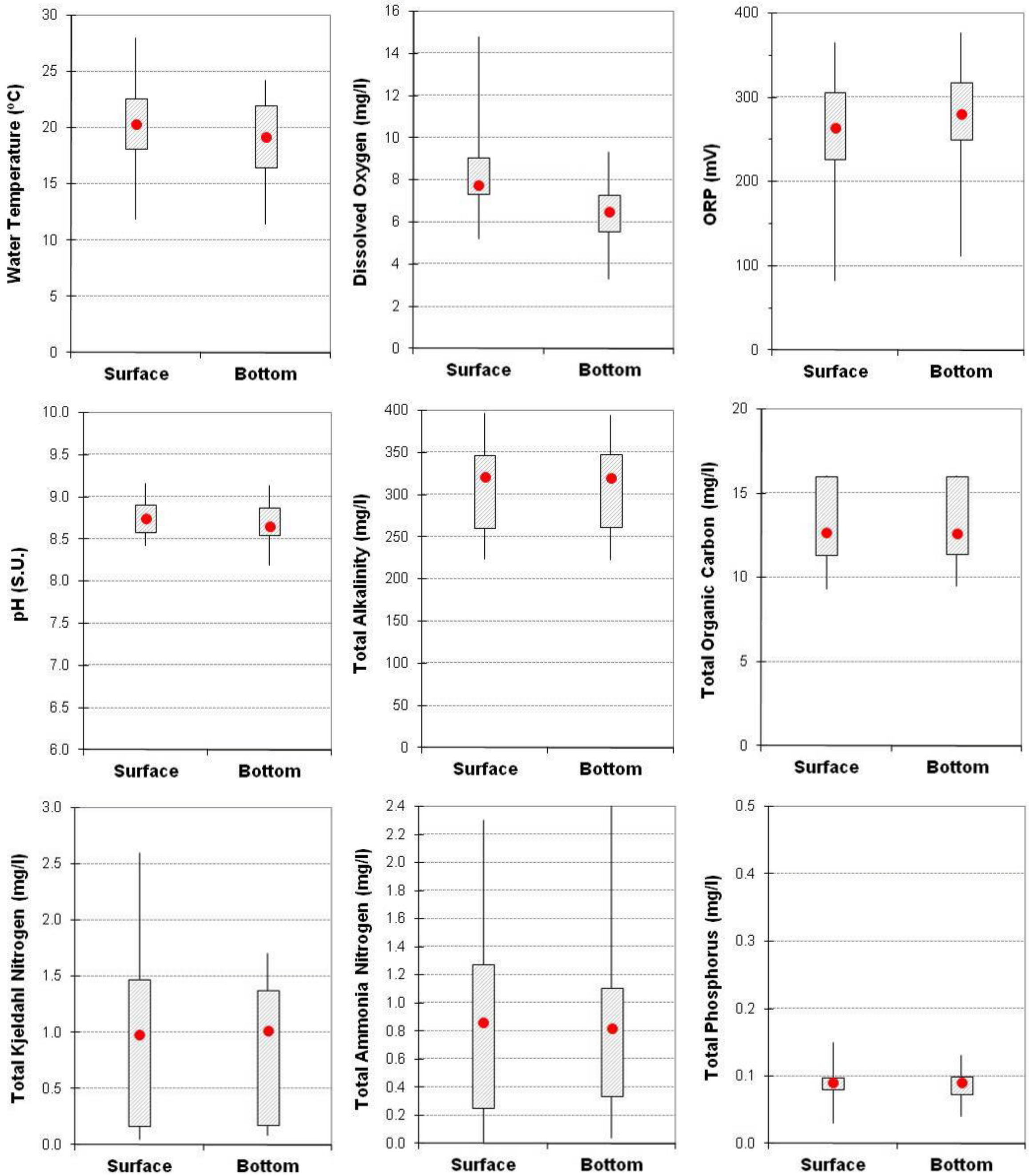


Plate 260. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, alkalinity, total organic carbon, total Kjeldahl nitrogen, total ammonia nitrogen, and total phosphorus measured in Bowman-Haley Reservoir at site BOWLKND1 during the summer months of 2001 through 2004 and 2010. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

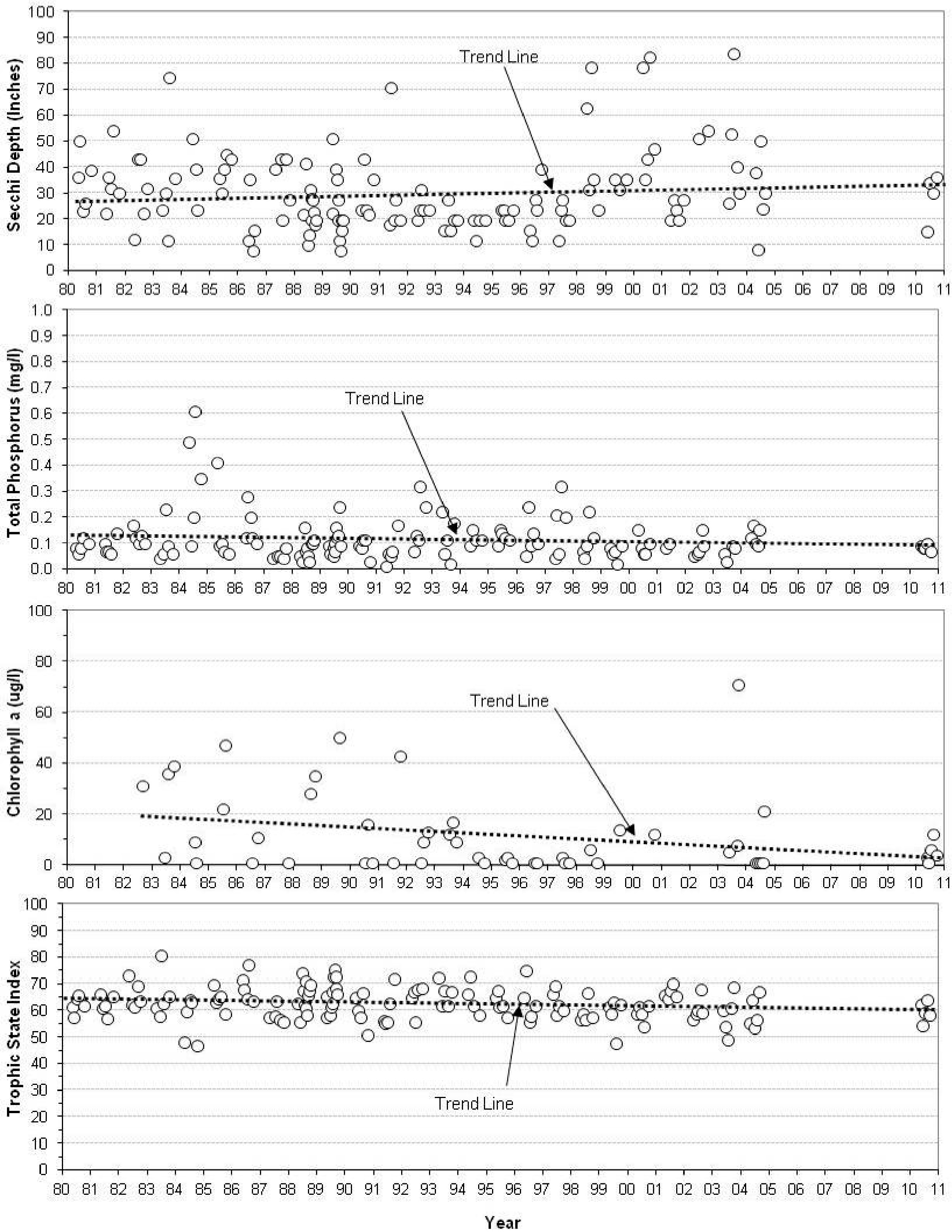


Plate 261. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Bowman-Haley Reservoir at the near-dam, ambient site (i.e., site BOWLKND1) over the 31-year period of 1980 through 2010.

Plate 262. Summary of runoff water quality conditions monitored in Alkali Creek upstream from Bowman-Haley Reservoir t at monitoring site BOWNFAKCK1 during the 2-year period 2001 through 2002**.**

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Water Temperature (°C)	0.1	2	20.0	20.0	14.0	26.0	29.4	0	0%
Dissolved Oxygen (mg/l)	0.1	2	7.7	7.7	6.2	9.1	≥ 5	0	0%
Dissolved Oxygen (% Sat.)	0.1	2	82.5	82.5	76.3	88.7	-----	-----	-----
Specific Conductance (umho/cm)	1	2	1595	1595	1460	1729	-----	-----	-----
pH (S.U.)	0.1	2	8.8	8.8	8.5	9.0	≥7.0 & ≤9.0	1	50%
Turbidity (NTUs)	1	1	-----	10	10	10	-----	-----	-----
Alkalinity, Total (mg/l)	7	2	273	273	137	408	-----	-----	-----
Ammonia, Total (mg/l)	0.02	1	-----	n.d.	n.d.	n.d.	2.0 (1,2), 0.45 (1,3)	0	0%
Carbon, Total Organic (mg/l)	0.05	2	22.05	22.05	18.00	26.10	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	1	-----	2354	2354	2354	-----	-----	-----
Hardness, Total (mg/l)	0.4	2	327.5	327.5	155.0	500.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	2	1.2	1.2	0.7	1.8	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	2	0.22	0.22	n.d.	0.44	1.0	0	0%
Phosphorus, Total (mg/l)	0.02	2	0.38	0.38	0.04	0.71	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	1	-----	n.d.	n.d.	n.d.	-----	-----	-----
Sulfate, Total (mg/l)	1	1	-----	1309	1309	1309	250	1	100%
Suspended Solids, Total (mg/l)	4	2	65	65	10	120	-----	-----	-----
Arsenic, Total (ug/l)	3	1	-----	n.d.	n.d.	n.d.	340(2), 150(3), 10(4)	0	0%
Copper, Total (ug/l)	2	1	-----	n.d.	n.d.	n.d.	43(2), 26(3)	0	0%
Iron, Total (ug/l)	7	1	-----	581	581	581	-----	-----	-----
Lead, Total (ug/l)	2	1	-----	2	2	2	370(2), 14(3)	0	0%
Manganese, Total (ug/l)	2	1	-----	217	217	217	-----	-----	-----
Zinc, Total (ug/l)	3	1	-----	n.d.	n.d.	n.d.	327(2,3)	0	0%

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.
(2) Acute criterion for aquatic life.
(3) Chronic criterion for aquatic life.
(4) Human health criterion for surface waters.
Note: North Dakota's WQS criteria for metals are based on total recoverable, some analyzed metal concentrations were dissolved. Listed criteria are given for comparison and were calculated using the median hardness.

(C) The pesticide scan (GCMS) includes: acetochlor, alachlor, atrazine, benfluralin, butylate, chlorpyrifos, cyanazine, cycloate, EPTC, hexazinone, isopropalin, metolachlor, metribuzin, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, profluralin, prometon, propachlor, propazine, simazine, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

Plate 263. Summary of runoff water quality conditions monitored in the Alkali Creek wetland upstream from Bowman-Haley Reservoir t at monitoring site BOWNFAKWD1 during 2001**.**

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[(A)]	Median	Min.	Max.	State WQS Criteria[(B)]	No. of WQS Exceedences	Percent WQS Exceedence
Water Temperature (°C)	0.1	2	20.0	20.0	13.0	27.0	29.4	0	0%
Dissolved Oxygen (mg/l)	0.1	2	7.5	7.5	6.6	8.4	≥ 5	0	0%
Dissolved Oxygen (% Sat.)	0.1	2	81.3	81.3	80.1	82.6	-----	-----	-----
Specific Conductance (umho/cm)	1	2	1676	1676	1560	1792	-----	-----	-----
pH (S.U.)	0.1	2	8.6	8.6	8.5	8.6	≥7.0 & ≤9.0	0	0%
Turbidity (NTUs)	1	1	-----	16	16	16	-----	-----	-----
Alkalinity, Total (mg/l)	7	1	-----	308	308	308	-----	-----	-----
Ammonia, Total (mg/l)	0.02	1	-----	n.d.	n.d.	n.d.	2.9 [(1,2)], 0.65 [(1,3)]	0	0%
Carbon, Total Organic (mg/l)	0.05	1	-----	19.00	19.00	19.00	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	1	-----	1818	1818	1818	-----	-----	-----
Hardness, Total (mg/l)	0.4	1	-----	394.0	394.0	394.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	1	-----	1.2	1.2	1.2	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	1	-----	n.d.	n.d.	n.d.	1.0	0	0%
Phosphorus, Total (mg/l)	0.02	1	-----	0.08	0.08	0.08	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	1	-----	n.d.	n.d.	n.d.	-----	-----	-----
Sulfate, Total (mg/l)	1	1	-----	1025	1025	1025	250	1	100%
Suspended Solids, Total (mg/l)	4	1	-----	18	18	18	-----	-----	-----
Arsenic, Total (ug/l)	3	1	-----	n.d.	n.d.	n.d.	340[(2)], 150[(3)], 10[(4)]	0	0%
Copper, Total (ug/l)	2	1	-----	n.d.	n.d.	n.d.	51[(2)], 30[(3)]	0	0%
Iron, Total (ug/l)	7	1	-----	689	689	689	-----	-----	-----
Lead, Total (ug/l)	2	1	-----	3	3	3	468[(2)], 18[(3)]	0	0%
Manganese, Total (ug/l)	2	1	-----	158	158	158	-----	-----	-----
Zinc, Total (ug/l)	3	1	-----	6	6	6	382[(2,3)]	0	0%

n.d. = Not detected.

[(A)] Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

[(B)] [(1)] Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.

[(2)] Acute criterion for aquatic life.

[(3)] Chronic criterion for aquatic life.

[(4)] Human health criterion for surface waters.

Note: North Dakota's WQS criteria for metals are based on total recoverable, some analyzed metal concentrations were dissolved. Listed criteria are given for comparison and were calculated using the median hardness.

[(C)] The pesticide scan (GCMS) includes: acetochlor, alachlor, atrazine, benfluralin, butylate, chlorpyrifos, cyanazine, cycloate, EPTC, hexazinone, isopropalin, metolachlor, metribuzin, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, profluralin, prometon, propachlor, propazine, simazine, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

Plate 264. Summary of runoff water quality conditions monitored in the North Fork Grand River upstream from Bowman-Haley Reservoir at monitoring site BOWNFNFGR1 during the 2-year period 2001 through 2002.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Water Temperature (°C)	0.1	4	18.3	17.0	12.0	27.0	29.4	0	0%
Dissolved Oxygen (mg/l)	0.1	5	8.6	8.8	6.9	9.6	≥ 5	0	0%
Dissolved Oxygen (% Sat.)	0.1	5	97.0	89.4	86.4	127.1	-----	-----	-----
Specific Conductance (umho/cm)	1	5	1906	1794	1445	2660	-----	-----	-----
pH (S.U.)	0.1	5	8.2	8.4	7.7	8.5	≥7.0 & ≤9.0	1	20%
Turbidity (NTUs)	1	2	40	40	35	45	-----	-----	-----
Alkalinity, Total (mg/l)	7	3	343	429	129	472	-----	-----	-----
Ammonia, Total (mg/l)	0.02	2	-----	n.d.	n.d.	n.d.	3.9 (1,2), 1.03 (1,3)	0	0%
Carbon, Total Organic (mg/l)	0.05	3	13.67	13.00	13.00	15.00	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	2	2547	2547	2391	2702	-----	-----	-----
Hardness, Total (mg/l)	0.4	3	372.3	482.0	137.0	498.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	3	0.8	0.7	0.7	0.9	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	3	-----	0.02	n.d.	0.18	1.0	0	0%
Phosphorus, Total (mg/l)	0.02	3	0.20	0.10	0.08	0.43	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	2	0.01	0.01	n.d.	0.02	-----	-----	-----
Sulfate, Total (mg/l)	1	1	-----	1350	1350	1350	250	1	100%
Suspended Solids, Total (mg/l)	4	3	82	58	53	134	-----	-----	-----
Arsenic, Total (ug/l)	3	1	-----	3	3	3	340(2), 150(3), 10(4)	0	0%
Copper, Total (ug/l)	2	1	-----	n.d.	n.d.	n.d.	62(2), 36(3)	0	0%
Iron, Total (ug/l)	7	1	-----	2130	2130	2130	-----	-----	-----
Lead, Total (ug/l)	2	1	-----	n.d.	n.d.	n.d.	605(2), 24(3)	0	0%
Manganese, Total (ug/l)	2	1	-----	724	724	724	-----	-----	-----
Zinc, Total (ug/l)	3	1	-----	8	8	8	454(2,3)	0	0%
Pesticide Scan (ug/l)(C)	0.05	1	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.
(2) Acute criterion for aquatic life.
(3) Chronic criterion for aquatic life.
(4) Human health criterion for surface waters.
Note: North Dakota's WQS criteria for metals are based on total recoverable, some analyzed metal concentrations were dissolved. Listed criteria are given for comparison and were calculated using the median hardness.

(C) The pesticide scan (GCMS) includes: acetochlor, alachlor, atrazine, benfluralin, butylate, chlorpyrifos, cyanazine, cycloate, EPTC, hexazinone, isopropalin, metolachlor, metribuzin, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, profluralin, prometon, propachlor, propazine, simazine, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

Plate 265. Summary of runoff water quality conditions monitored in Spring Creek upstream from Bowman-Haley Reservoir at monitoring site BOWNFSPCK1 during 2001**.**

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Water Temperature (°C)	0.1	5	21.2	21.0	12.0	31.0	29.4	1	20%
Dissolved Oxygen (mg/l)	0.1	5	7.8	7.6	6.3	8.8	≥ 5	0	0%
Dissolved Oxygen (% Sat.)	0.1	5	88.0	85.4	70.8	117.7	-----	-----	-----
Specific Conductance (umho/cm)	1	5	1805	1638	1332	2800	-----	-----	-----
pH (S.U.)	0.1	5	8.1	8.3	7.4	8.7	≥7.0 & ≤9.0	0	0%
Turbidity (NTUs)	1	2	41	41	36	46	-----	-----	-----
Alkalinity, Total (mg/l)	7	2	444	444	408	479	-----	-----	-----
Ammonia, Total (mg/l)	0.02	2	-----	n.d.	n.d.	n.d.	4.7 [1,2], 0.96 [1,3]	0	0%
Carbon, Total Organic (mg/l)	0.05	2	16.50	16.50	15.00	18.00	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	2	2603	2603	2209	2997	-----	-----	-----
Hardness, Total (mg/l)	0.4	2	797.5	797.5	679.0	916.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	2	1.6	1.6	1.4	1.7	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	2	-----	0.01	n.d.	0.02	1.0	0	0%
Phosphorus, Total (mg/l)	0.02	2	0.16	0.16	0.13	0.19	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	2	-----	0.01	n.d.	0.02	-----	-----	-----
Sulfate, Total (mg/l)	1	1	-----	1254	1254	1254	250	1	100%
Suspended Solids, Total (mg/l)	4	2	75	75	56	94	-----	-----	-----
Arsenic, Total (ug/l)	3	1	-----	3	3	3	340[2], 150[3], 10[4]	0	0%
Copper, Total (ug/l)	2	1	-----	n.d.	n.d.	n.d.	99[2], 55[3]	0	0%
Iron, Total (ug/l)	7	1	-----	2243	2243	2243	-----	-----	-----
Lead, Total (ug/l)	2	1	-----	n.d.	n.d.	n.d.	1148[2], 45[3]	0	0%
Manganese, Total (ug/l)	2	1	-----	615	615	615	-----	-----	-----
Zinc, Total (ug/l)	3	1	-----	5	5	5	696[2,3]	0	0%
Pesticide Scan (ug/l)[C]	0.05	1	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

[A] Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

[B] [1] Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.
[2] Acute criterion for aquatic life.
[3] Chronic criterion for aquatic life.
[4] Human health criterion for surface waters.
Note: North Dakota's WQS criteria for metals are based on total recoverable, some analyzed metal concentrations were dissolved. Listed criteria are given for comparison and were calculated using the median hardness.

[C] The pesticide scan (GCMS) includes: acetochlor, alachlor, atrazine, benfluralin, butylate, chlorpyrifos, cyanazine, cycloate, EPTC, hexazinone, isopropalin, metolachlor, metribuzin, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, profluralin, prometon, propachlor, propazine, simazine, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

Plate 266. Summary of water quality conditions monitored in Pipestem Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site PIPLKND1) from May to September during the 10-year period 2001 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at ½ the measured Secchi depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	30	1450.0	1448.3	1442.1	1470.1	-----	-----	-----
Water Temperature (°C)	0.1	528	18.4	19.0	6.7	27.8	29.4	0	0%
Dissolved Oxygen (mg/l)	0.1	528	6.6	7.3	0.0	21.3	≥ 5	123	23%
Dissolved Oxygen (% Sat.)	0.1	528	72.2	81.3	0.0	282.2	-----	-----	-----
Specific Conductance (umho/cm)	1	528	1024	961	364	1438	-----	-----	-----
pH (S.U.)	0.1	489	8.2	8.3	6.7	9.4	≥7.0 & ≤9.0	8, 7	2%, 1%
Turbidity (NTUs)	1	389	9	6	n.d.	181	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	376	332	366	-70	452	-----	-----	-----
Secchi Depth (in.)	1	30	54	46	15	138	-----	-----	-----
Alkalinity, Total (mg/l)	7	50	273	274	146	402	-----	-----	-----
Ammonia, Total (mg/l)	0.02	43	0.41	0.37	n.d.	1.40	4.71 (1,2), 1.09 (1,3)	0, 2	0%, 7%
Carbon, Total Organic (mg/l)	0.05	35	15.33	15.00	10.30	27.10	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	316	14	11	n.d.	164	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab Determined	1	23	22	11	n.d.	127	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	23	622	608	350	1088	-----	-----	-----
Hardness, Total (mg/l)	0.4	16	463.6	483.5	274.0	545.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	52	1.5	1.4	n.d.	3.2	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	52	-----	0.02	n.d.	0.97	1.0	0	0%
Phosphorus, Total (mg/l)	0.02	52	0.44	0.42	0.13	1.10	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	0.33	0.32	n.d.	0.81	-----	-----	-----
Sulfate, Total (mg/l)	1	21	210	213	117	360	250	4	19%
Suspended Solids, Total (mg/l)	4	52	-----	6	n.d.	27	-----	-----	-----
Arsenic, Total (ug/l)	3	5	-----	7	n.d.	11	340(2), 150(3), 10(4)	0, 0, 1	0%, 0%, 20%
Beryllium, Dissolved (ug/l)	0.5	4	-----	n.d.	n.d.	n.d.	4(4)	0	0%
Cadmium, Dissolved (ug/l)	0.5	4	-----	n.d.	n.d.	6.0	27(2), 8.5(3)	0	0%
Chromium, Dissolved (ug/l)	2	4	-----	n.d.	n.d.	n.d.	6,554(2), 313(3)	0	0%
Copper, Total (ug/l)	2	5	-----	n.d.	n.d.	n.d.	62(2), 36(3)	0	0%
Lead, Total (ug/l)	2	5	-----	n.d.	n.d.	n.d.	607(2), 24(3)	0	0%
Mercury, Total (ug/l)	0.02	5	-----	n.d.	n.d.	n.d.	1.7(2), 0.012(3), 0.05(4)	0	0%
Zinc, Total (ug/l)	3	5	-----	n.d.	n.d.	7	455(2,3)	0	0%
Microcystin (ug/l)	0.2	9	-----	n.d.	n.d.	0.2	-----	-----	-----
Alachlor, Total (ug/l)(C)	0.05	9	-----	n.d.	n.d.	n.d.	2(4)	0	0%
Atrazine, Total (ug/l)(C)	0.05	9	0.10	0.08	n.d.	0.22	3(4)	0	0%
Metolachlor, Total (ug/l)(C)	0.05	9	-----	n.d.	n.d.	n.d.	40(4)	0	0%
Pesticide Scan (ug/l)(D)	0.05	9	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.

(2) Acute criterion for aquatic life.

(3) Chronic criterion for aquatic life.

Note: North Dakota's chronic WQS criterion for Mercury was below the detection limit during the reporting period.

(4) Human health criterion for surface waters.

Note: North Dakota's WQS criteria for metals are based on total recoverable, some analyzed metal concentrations were dissolved. Listed criteria are given for comparison and were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, atrazine, benfluralin, butylate, chlorpyrifos, cyanazine, cycloate, EPTC, hexazinone, isopropalin, metribuzin, metolachlor, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, profluralin, prometon, propachlor, propazine, simazine, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted percent exceedence indicates use impairment based on State of North Dakota's 2010 Section 303(d) impairment assessment criteria.

Plate 267. Summary of water quality conditions monitored in Pipestem Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site PIPLKML1) from May to September during the 10-year period 2001 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at ½ the measured Secchi depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	27	1450.0	1448.3	1442.1	1470.1	-----	-----	-----
Water Temperature (°C)	0.1	337	18.9	18.6	6.5	27.7	29.4	0	0%
Dissolved Oxygen (mg/l)	0.1	337	7.4	7.6	0.2	14.5	≥ 5	33	10%
Dissolved Oxygen (% Sat.)	0.1	337	81.7	84.5	2.2	191.5	-----	-----	-----
Specific Conductance (umho/cm)	1	336	1017	959	544	1437	-----	-----	-----
pH (S.U.)	0.1	309	8.3	8.3	7.4	8.9	≥7.0 & ≤9.0	0	0%
Turbidity (NTUs)	1	245	13	10	n.d.	66	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	240	343	366	142	417	-----	-----	-----
Secchi Depth (in.)	1	30	37	33	15	79	-----	-----	-----
Alkalinity, Total (mg/l)	7	5	311	355	210	374	-----	-----	-----
Ammonia, Total (mg/l)	0.02	5	0.17	0.18	0.04	0.27	4.71 (1,2), 1.09 (1,3)	0, 1	0%, 7%
Carbon, Total Organic (mg/l)	0.05	5	16.60	17.00	13.00	20.00	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	218	19	19	n.d.	82	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab Determined	1	3	7	6	5	9	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	5	930	993	527	1088	-----	-----	-----
Hardness, Total (mg/l)	0.4	5	433.2	482.0	290.0	508.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	5	1.4	1.3	1.0	1.8	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	5	0.23	0.07	0.02	0.67	1.0	0	0%
Phosphorus, Total (mg/l)	0.02	5	0.50	0.61	0.16	0.75	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	5	0.43	0.51	0.13	0.67	-----	-----	-----
Sulfate, Total (mg/l)	1	3	304	331	210	370	250	4	44%
Suspended Solids, Total (mg/l)	4	5	18	14	9	37	-----	-----	-----
Arsenic, Total (ug/l)	3	3	10	13	2	14	340(2), 150(3), 10(4)	0, 0, 2	0%, 0%, 67%
Copper, Total (ug/l)	2	3	-----	n.d.	n.d.	6	61(2), 35(3)	0	0%
Lead, Total (ug/l)	2	3	-----	n.d.	n.d.	n.d.	605(2), 24(3)	0	0%
Mercury, Total (ug/l)	0.02	2	0.02	0.02	0.01	0.02	1.7(2), 0.012(3), 0.05(4)	0	0%
Zinc, Total (ug/l)	3	3	4	4	4	4	454(2,3)	0	0%
Pesticide Scan (ug/l)(D)	0.05	2	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.
(2) Acute criterion for aquatic life.
(3) Chronic criterion for aquatic life.
Note: North Dakota's chronic WQS criterion for Mercury was below the detection limit during the reporting period.
(4) Human health criterion for surface waters.
Note: North Dakota's WQS criteria for metals are based on total recoverable, some analyzed metal concentrations were dissolved. Listed criteria are given for comparison and were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, atrazine, benfluralin, butylate, chlorpyrifos, cyanazine, cycloate, EPTC, hexazinone, isopropalin, metribuzin, metolachlor, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, profluralin, prometon, propachlor, propazine, simazine, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted percent exceedence indicates use impairment based on State of North Dakota's 2010 Section 303(d) impairment assessment criteria.

Plate 268. Summary of water quality conditions monitored in Pipestem Reservoir at the up-lake ambient monitoring location (i.e., site PIPLKUP1) from May to September during the 10-year period 2001 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at ½ the measured Secchi depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	5	1451.7	1448.6	1442.1	1463.4	-----	-----	-----
Water Temperature (°C)	0.1	78	18.1	17.9	9.4	28.5	29.4	0	0%
Dissolved Oxygen (mg/l)	0.1	78	8.3	8.6	0.4	12.0	≥ 5	5	6%
Dissolved Oxygen (% Sat.)	0.1	78	89.2	88.7	4.3	123.3	-----	-----	-----
Specific Conductance (umho/cm)	1	78	885	823	370	1313	-----	-----	-----
pH (S.U.)	0.1	74	8.1	8.2	7.0	9.0	≥7.0 & ≤9.0	4, 1	5%, 1%
Turbidity (NTUs)	1	5	14	12	5	27	-----	-----	-----
Secchi Depth (in.)	1	9	30	30	8	60	-----	-----	-----
Alkalinity, Total (mg/l)	7	5	322	362	209	386	-----	-----	-----
Ammonia, Total (mg/l)	0.02	5	0.14	0.12	0.04	0.28	5.95 (1,2), 1.43 (1,3)	0	0%
Carbon, Total Organic (mg/l)	0.05	5	17.00	18.00	12.00	21.00	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	52	23	6	2	101	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab Determined	1	3	8	6	3	14	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	5	960	1034	523	1173	-----	-----	-----
Hardness, Total (mg/l)	0.4	5	444.4	497.0	280.0	525.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	5	1.4	1.4	0.9	2.0	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	5	0.26	0.09	0.02	0.82	1.0	0	0%
Phosphorus, Total (mg/l)	0.02	5	0.49	0.64	0.15	0.73	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	5	0.40	0.50	0.16	0.63	-----	-----	-----
Sulfate, Total (mg/l)	1	3	299	343	202	352	250	2	67%
Suspended Solids, Total (mg/l)	4	5	24	20	6	48	-----	-----	-----
Arsenic, Total (ug/l)	3	3	9	11	3	12	340(2), 150(3), 10(4)	0, 0, 2	0%, 0%, 67%
Copper, Total (ug/l)	2	3	-----	n.d.	n.d.	n.d.	63(2), 37(3)	0	0%
Lead, Total (ug/l)	2	3	-----	n.d.	n.d.	n.d.	629(2), 24(3)	0	0%
Mercury, Total (ug/l)	0.02	2	-----	0.02	n.d.	0.03	1.7(2), 0.012(3), 0.05(4)	0	0%
Zinc, Total (ug/l)	3	3	-----	4	n.d.	6	466(2,3)	0	0%
Pesticide Scan (ug/l)(D)	0.05	2	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.
(2) Acute criterion for aquatic life.
(3) Chronic criterion for aquatic life.
Note: North Dakota's chronic WQS criterion for Mercury was below the detection limit during the reporting period.
(4) Human health criterion for surface waters.
Note: North Dakota's WQS criteria for metals are based on total recoverable, some analyzed metal concentrations were dissolved. Listed criteria are given for comparison and were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, atrazine, benfluralin, butylate, chlorpyrifos, cyanazine, cycloate, EPTC, hexazinone, isopropalin, metribuzin, metolachlor, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, profluralin, prometon, propachlor, propazine, simazine, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted percent exceedence indicates use impairment based on State of North Dakota's 2010 Section 303(d) impairment assessment criteria.

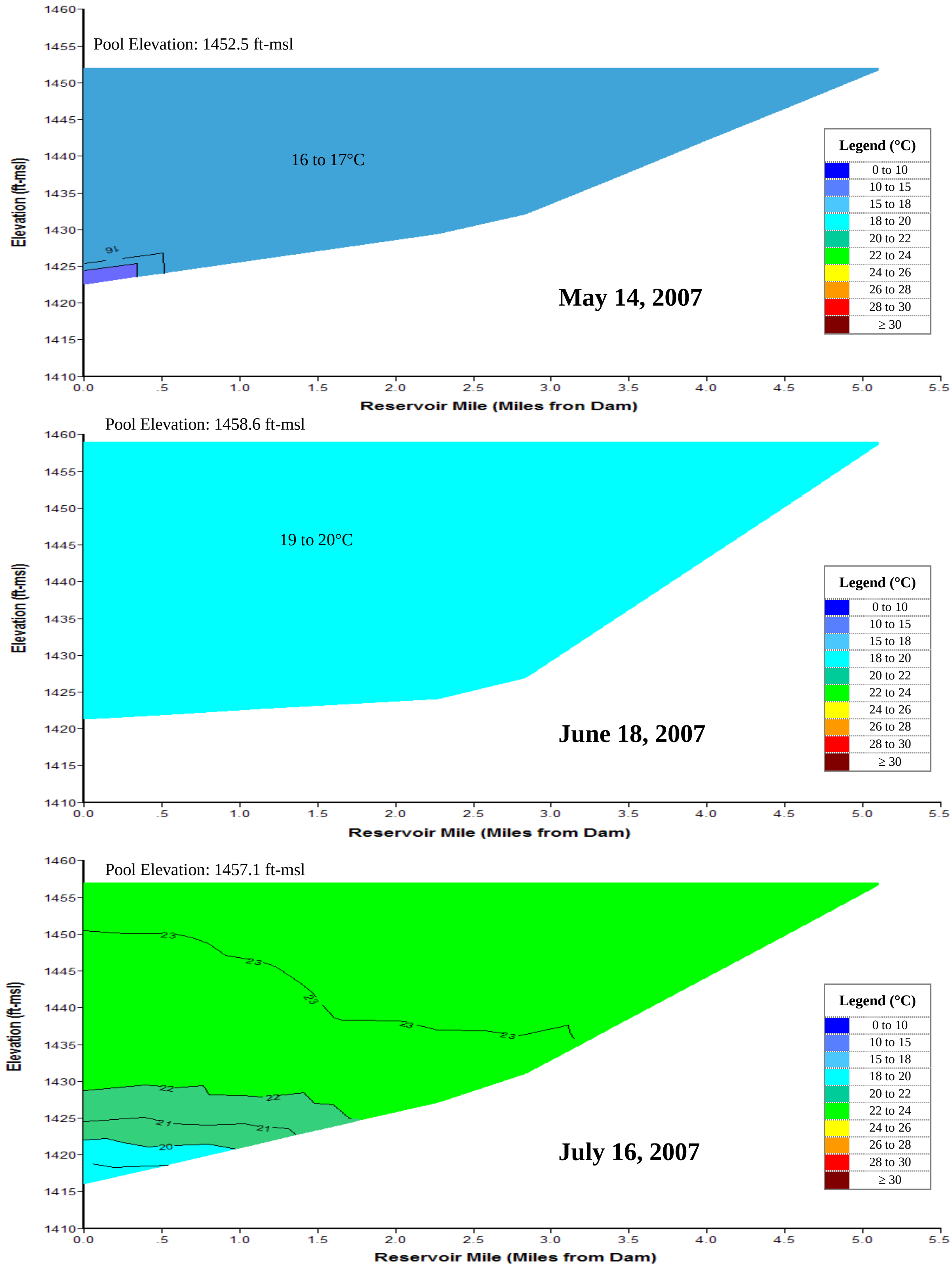
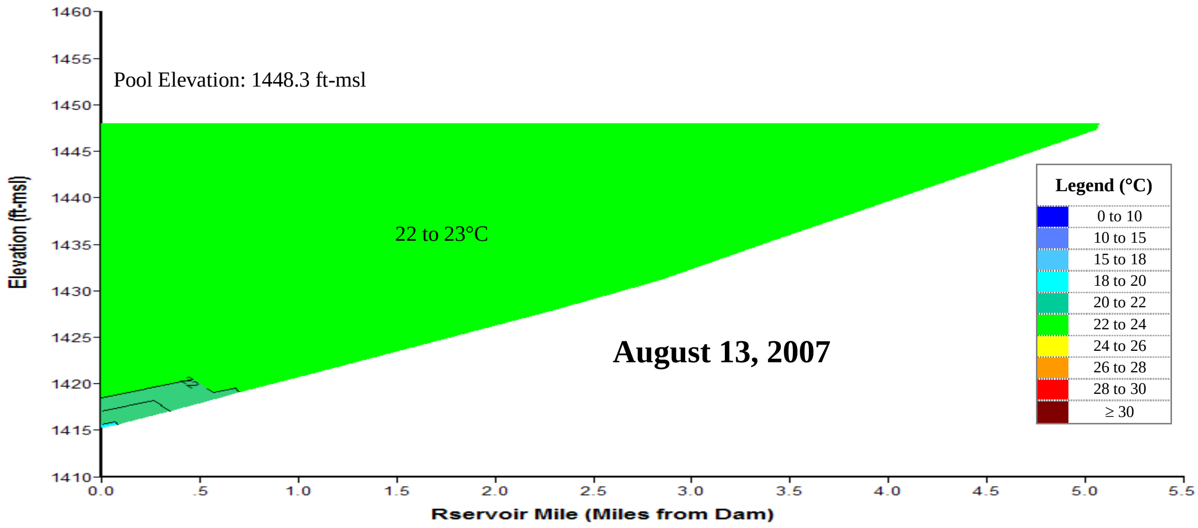


Plate 269. Longitudinal water temperature (°C) contour plots of Pipestem Reservoir based on depth-profile water temperatures measured at sites PIPLKND1 and PIPLKML1 in 2007.



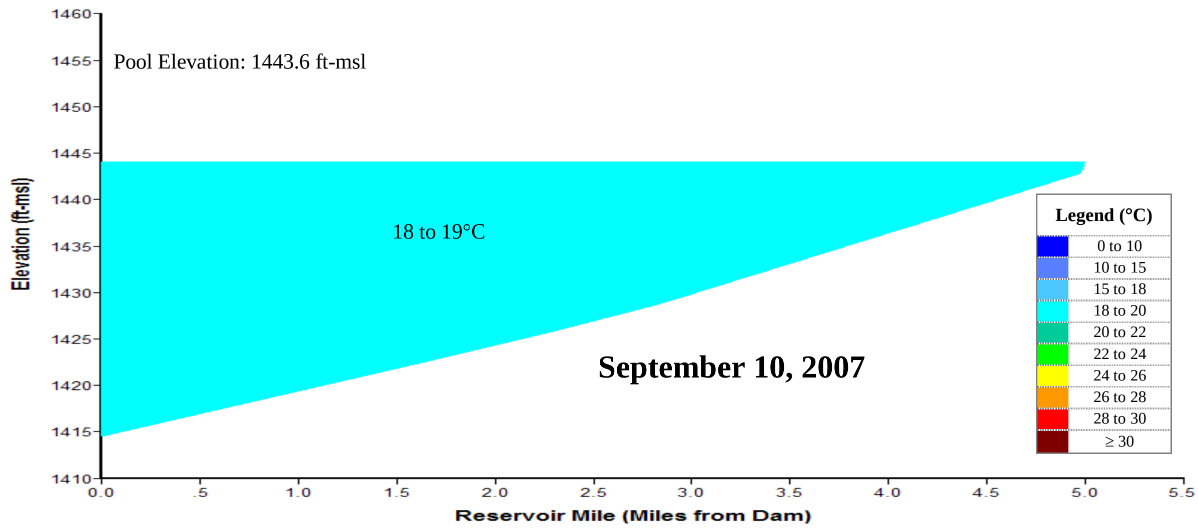


Plate 269. (Continued).

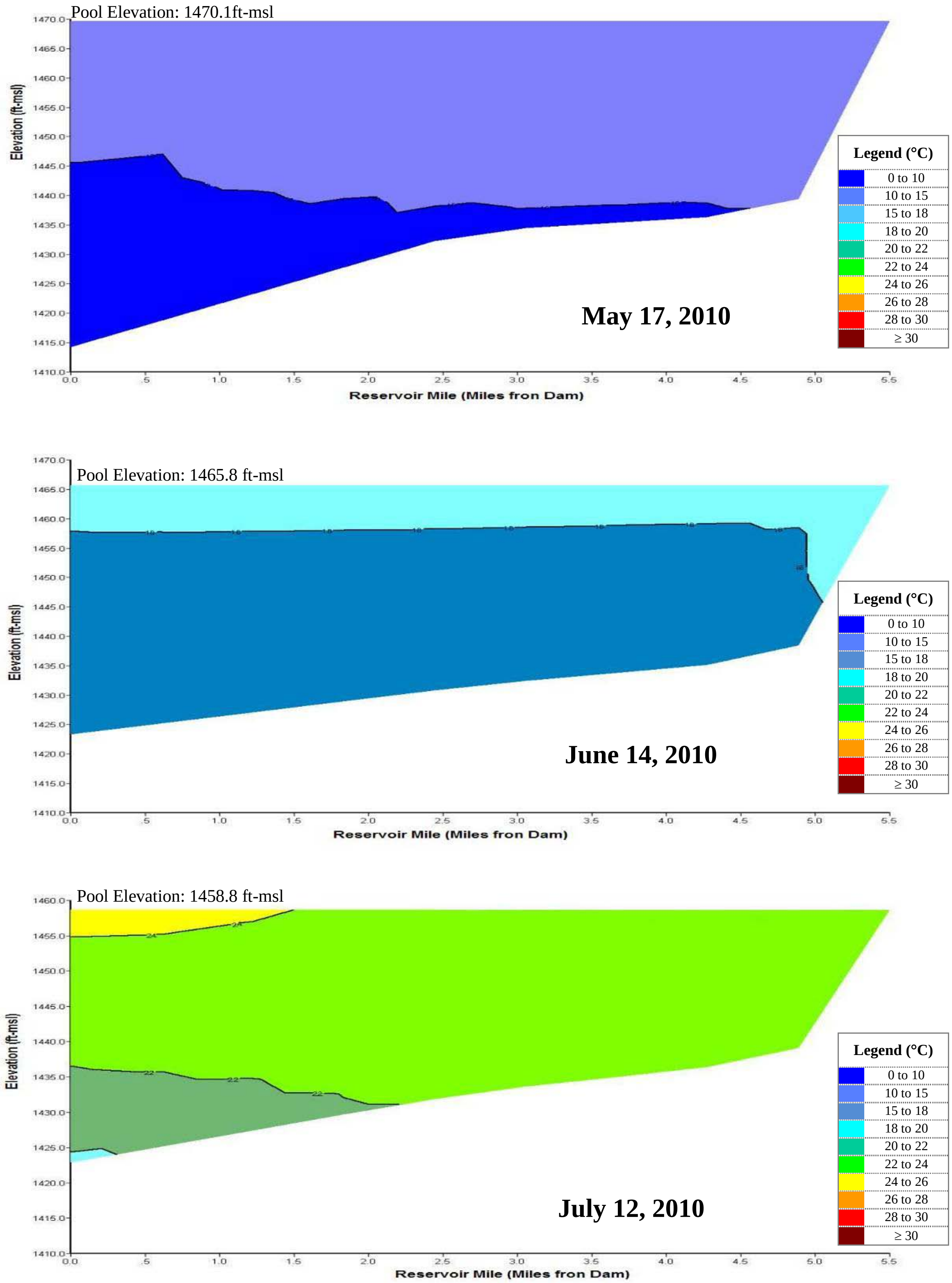
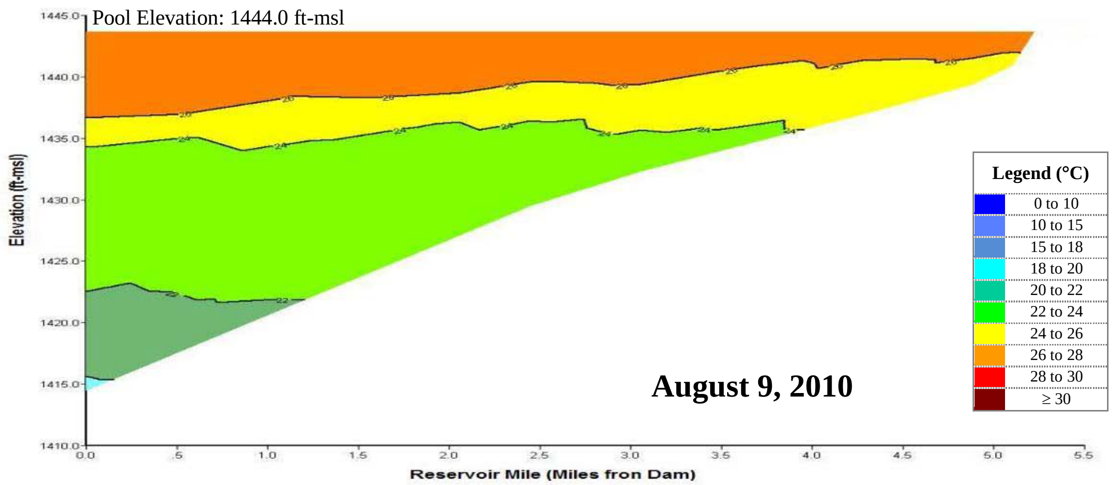


Plate 270. Longitudinal water temperature (°C) contour plots of Pipestem Reservoir based on depth-profile water temperatures measured at sites PIPLKND1 and PIPLKML1 in 2010.



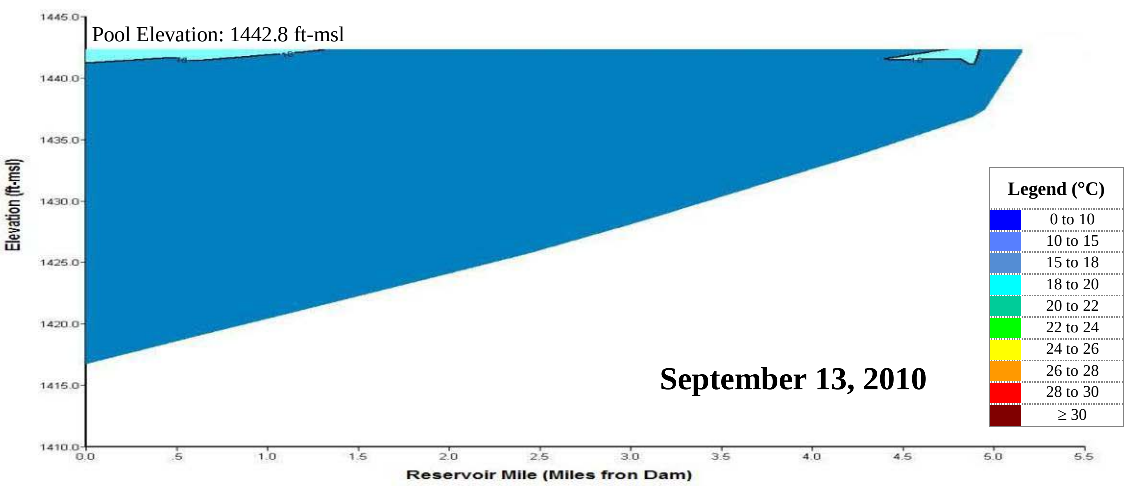


Plate 270. (Continued).

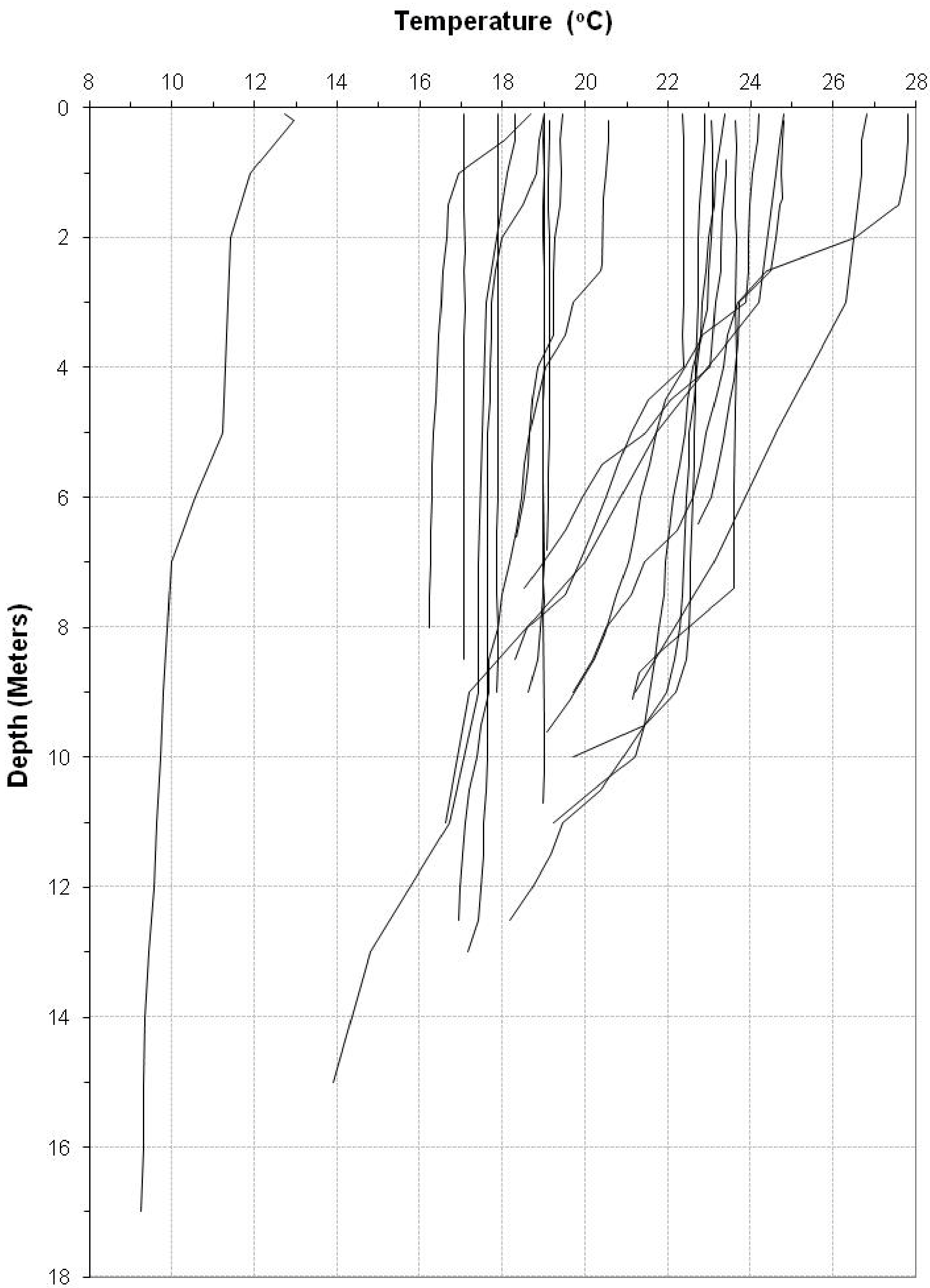


Plate 271. Temperature depth profiles for Pipestem Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., PIPLKND1) during the summer over the 10-year period of 2001 through 2010.

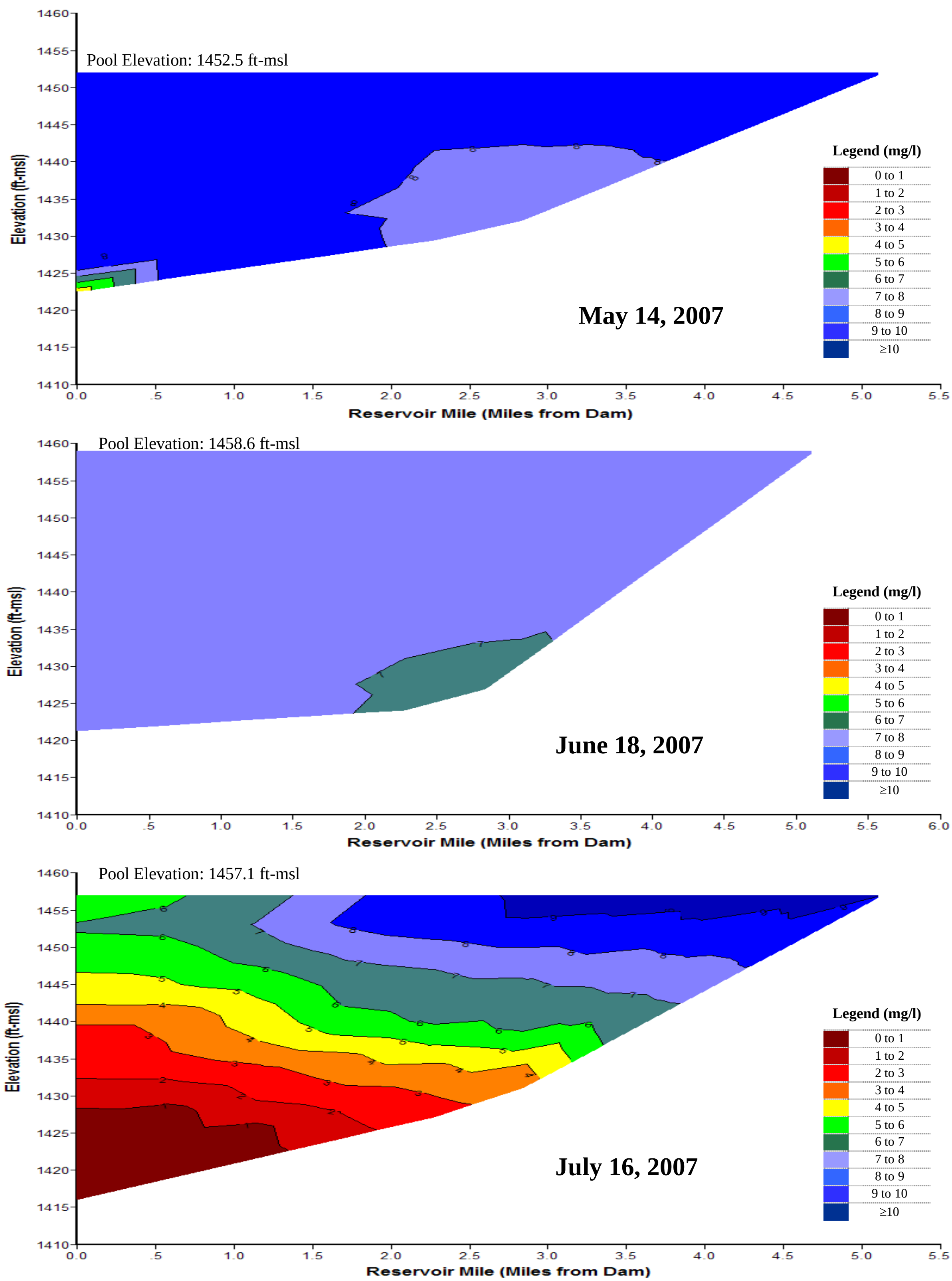
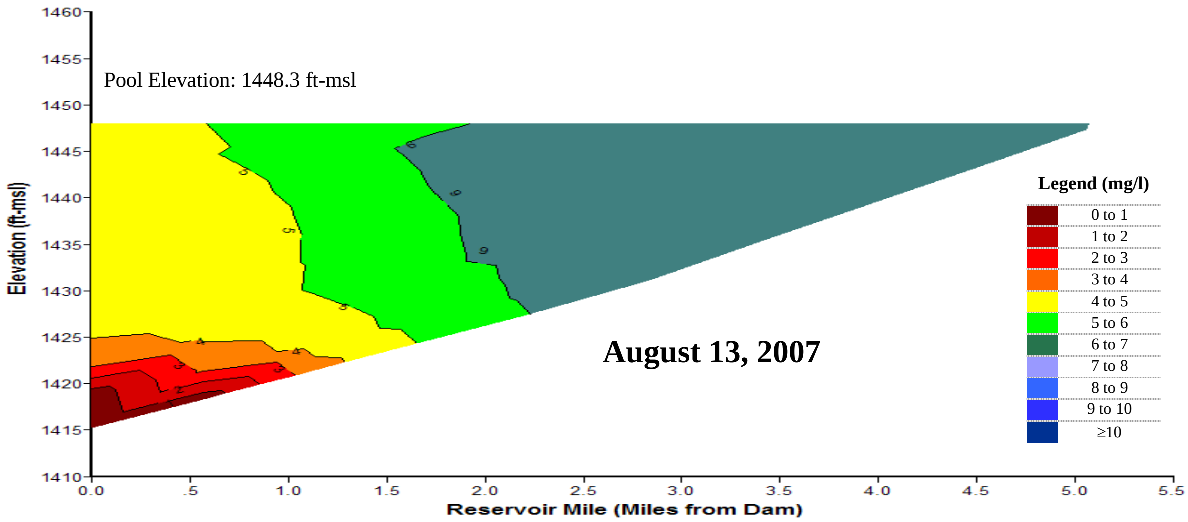


Plate 272. Longitudinal dissolved oxygen (mg/l) contour plots of Pipestem Reservoir based on depth-profile dissolved oxygen concentrations measured at sites PIPLKND1 and PIPLKML1 in 2007.



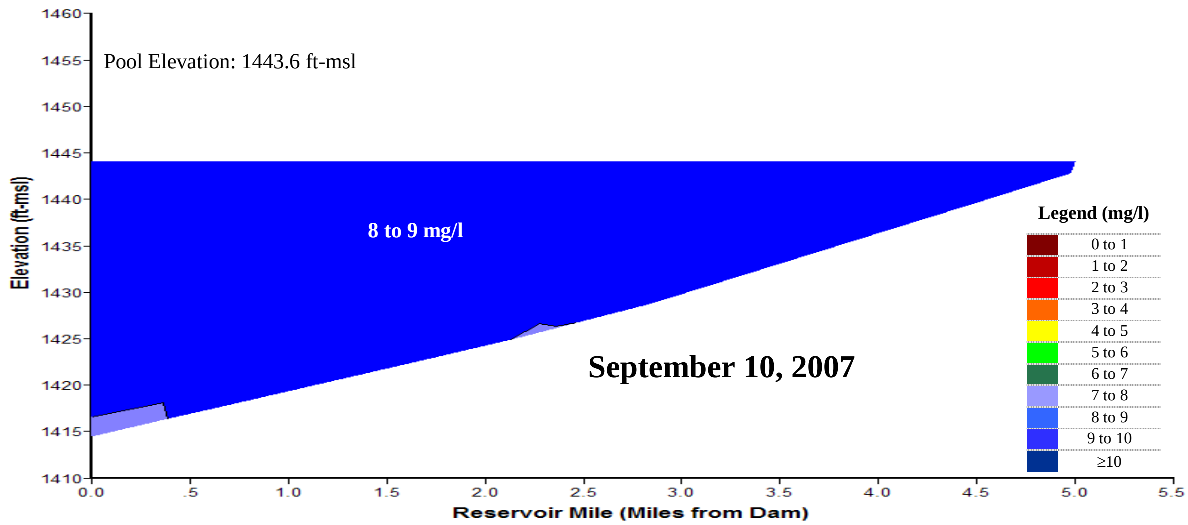


Plate 272. (Continued).

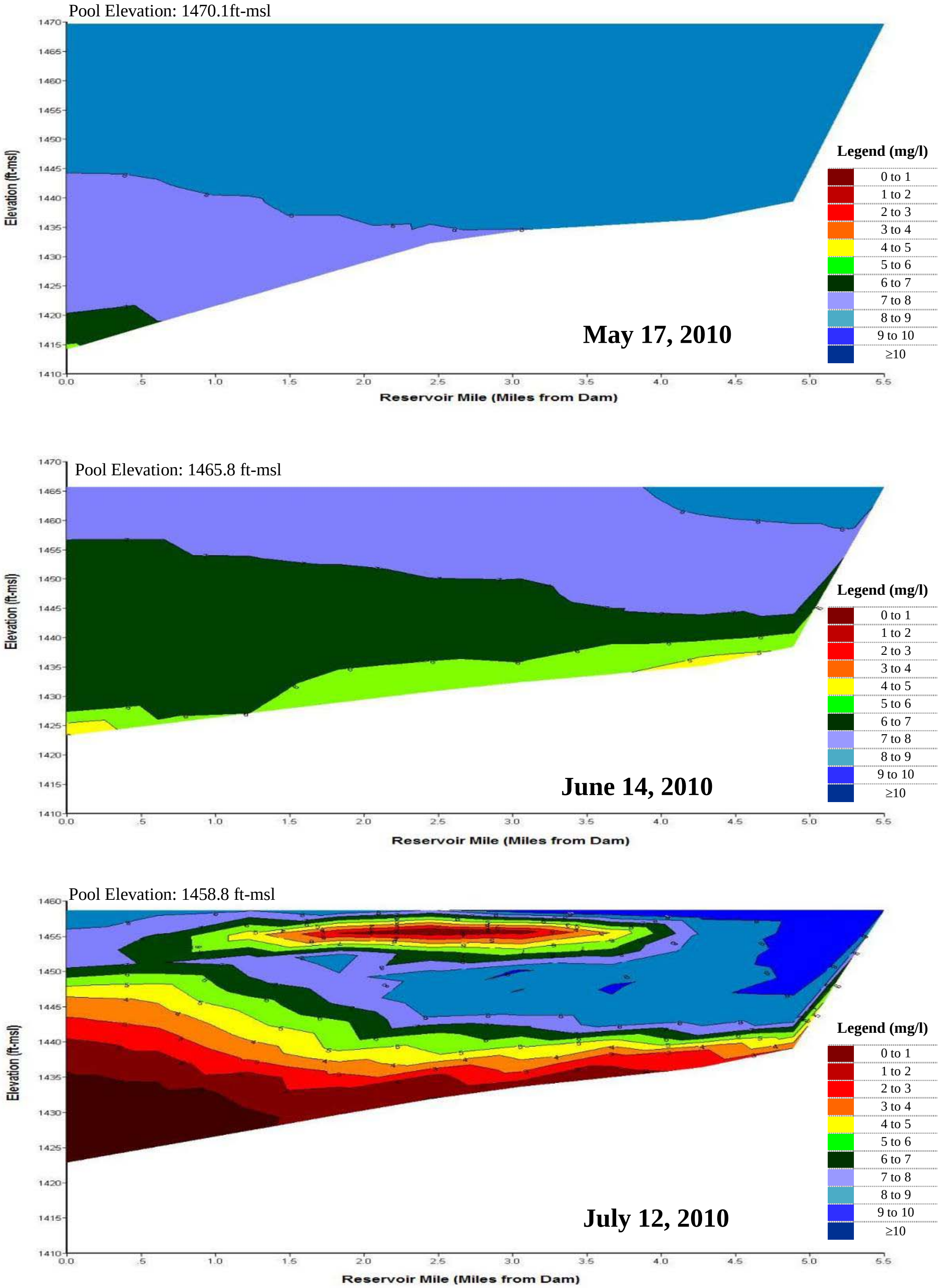
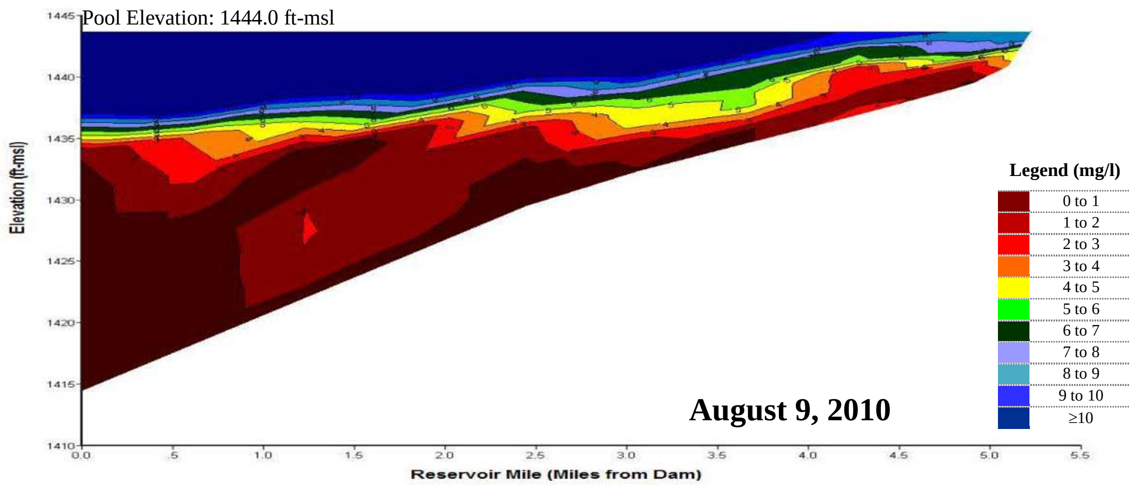


Plate 273. Longitudinal dissolved oxygen (mg/l) contour plots of Pipestem Reservoir based on depth-profile dissolved oxygen concentrations measured at sites PIPLKND1 and PIPLKML1 in 2010.



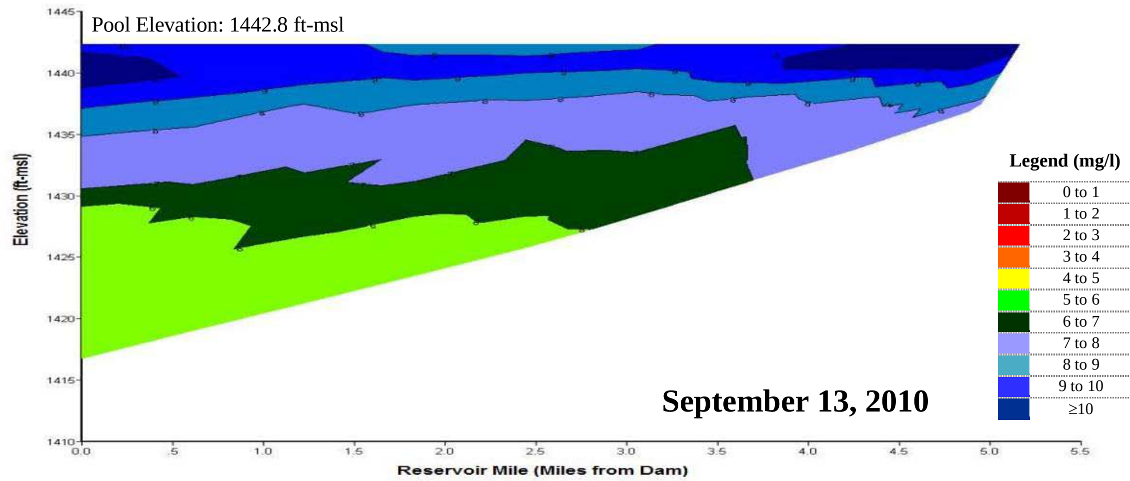


Plate 273. (Continued).

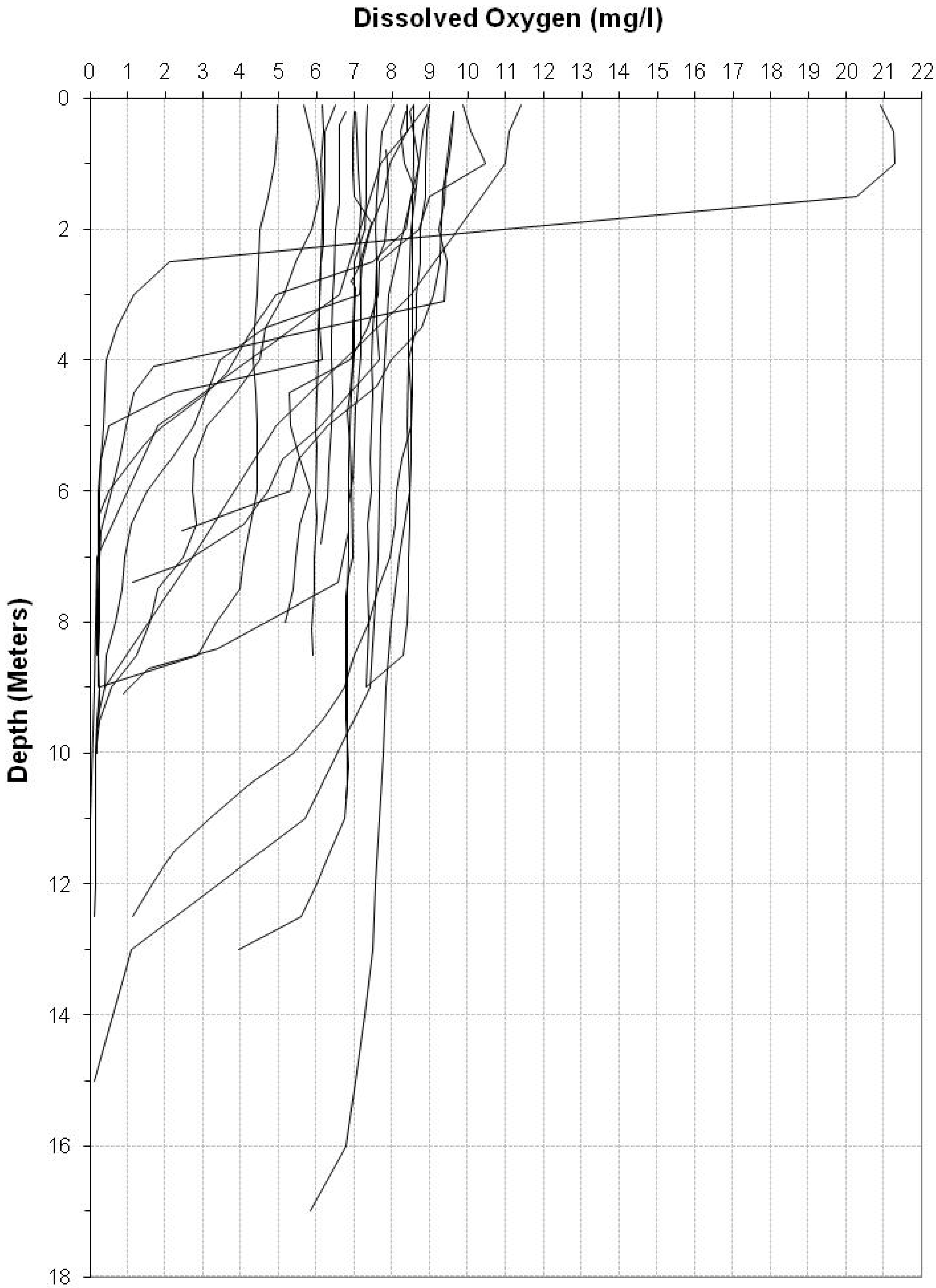


Plate 274. Dissolved oxygen depth profiles for Pipestem Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., PIPLKND1) during the summer over the 10-year period of 2001 through 2010.

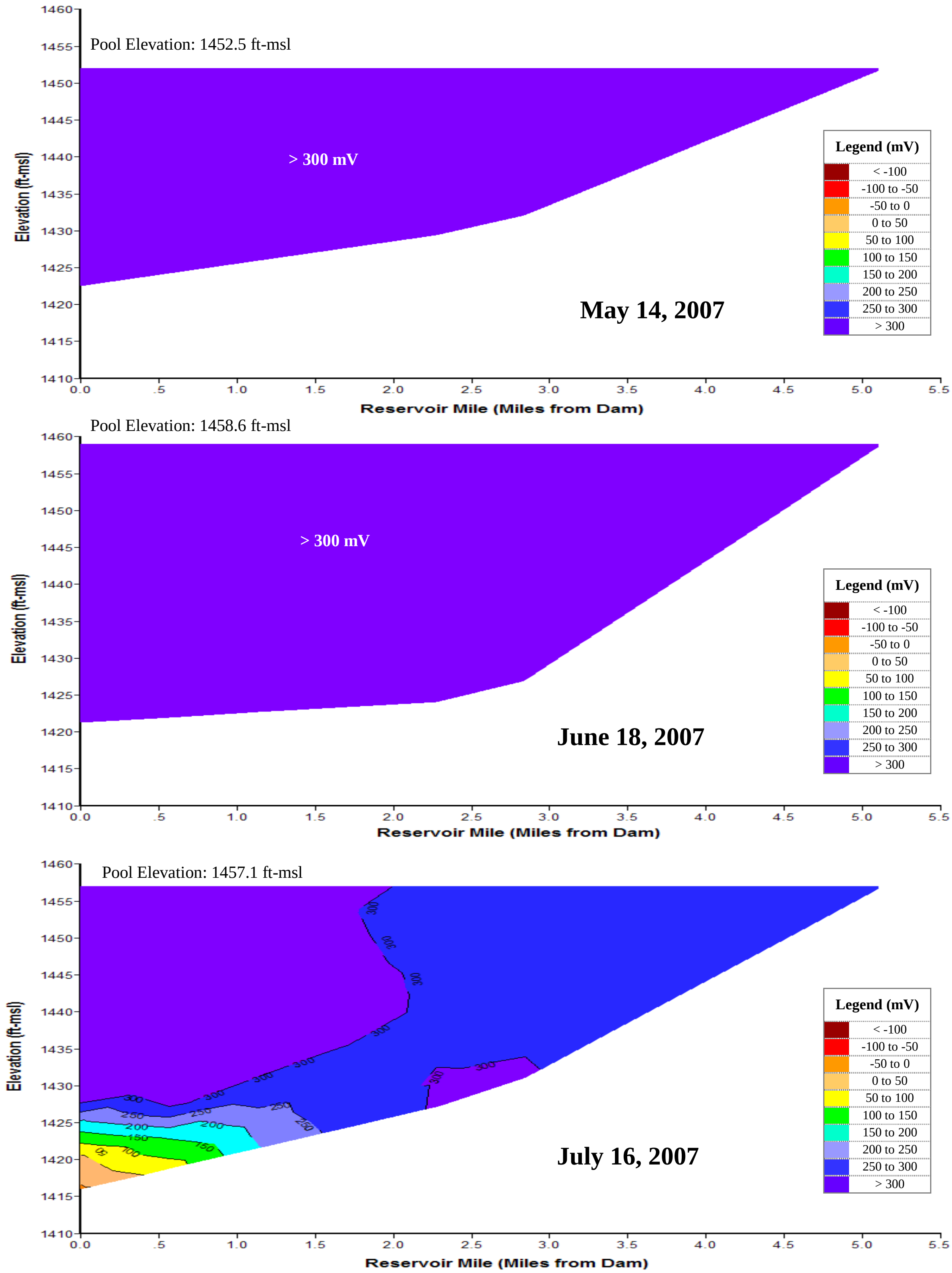
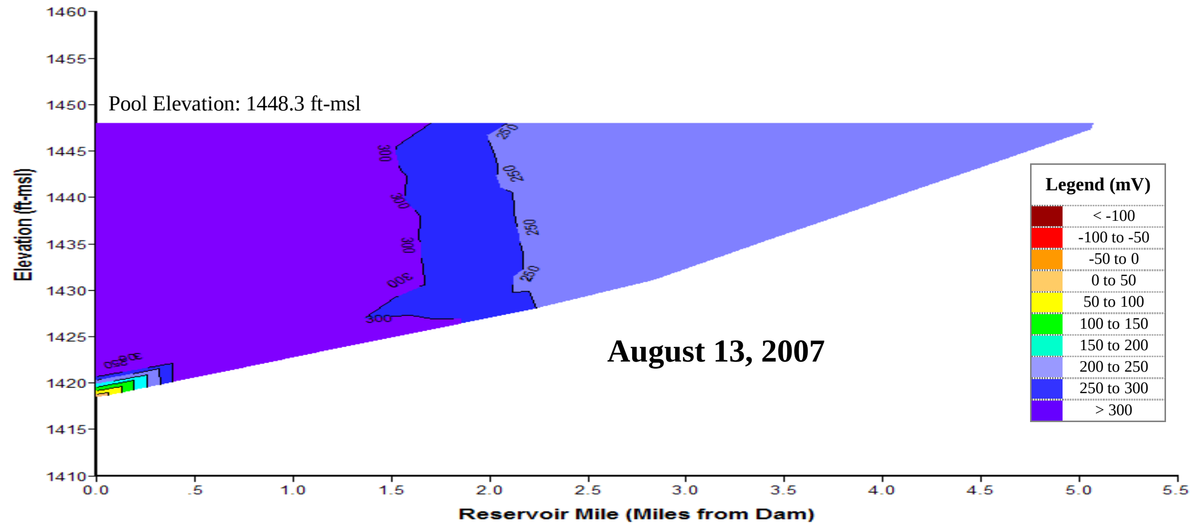


Plate 275. Longitudinal oxidation-reduction potential (mV) contour plots of Pipestem Reservoir based on depth-profile dissolved oxygen concentrations measured at sites PIPLKND1 and PIPLKML1 in 2007.



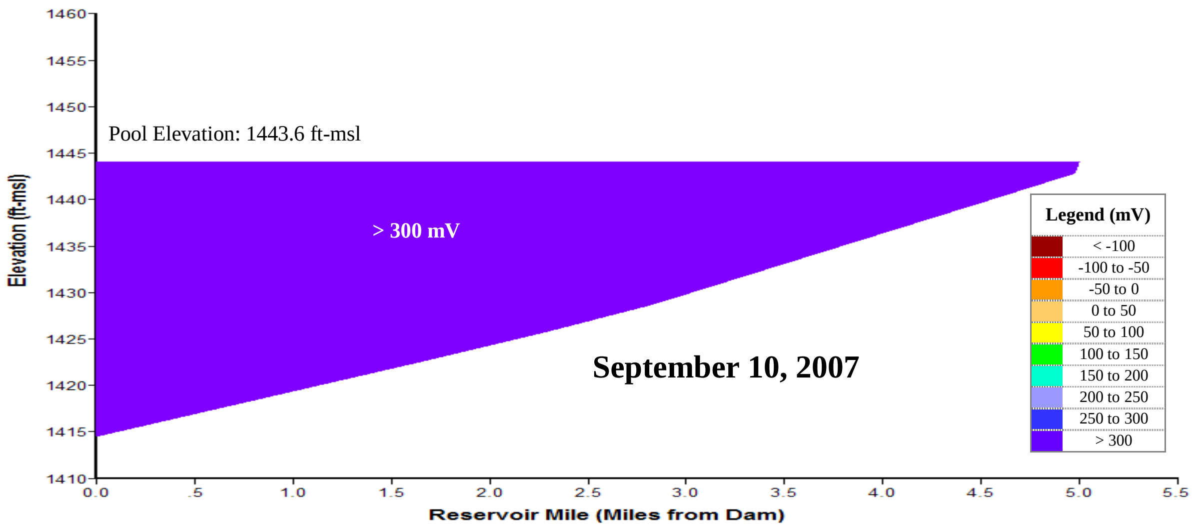
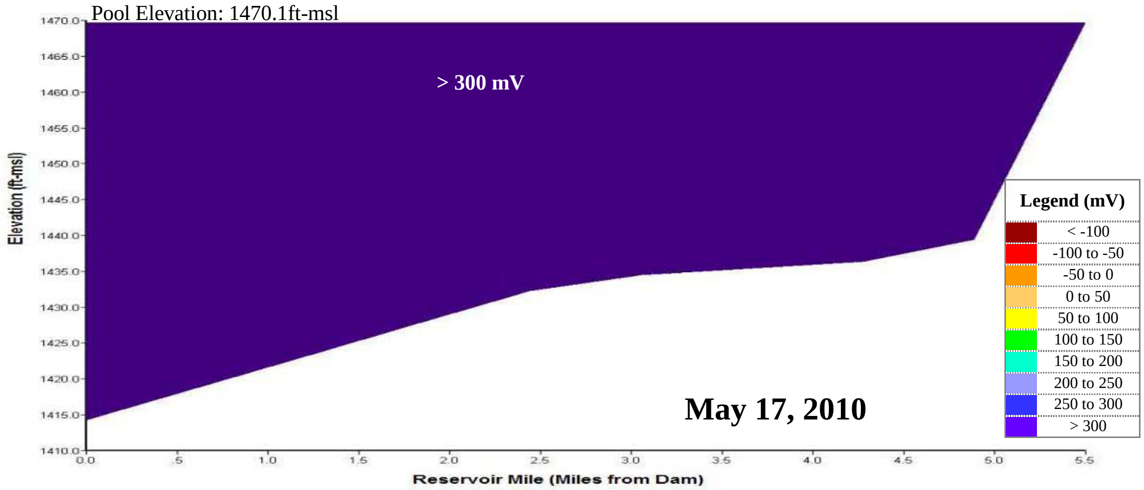
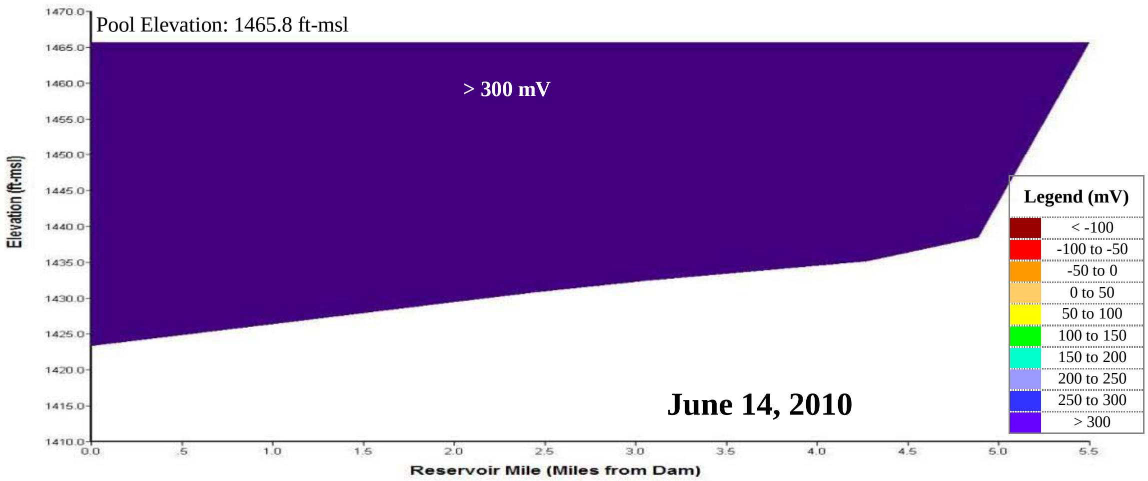


Plate 275. (Continued).





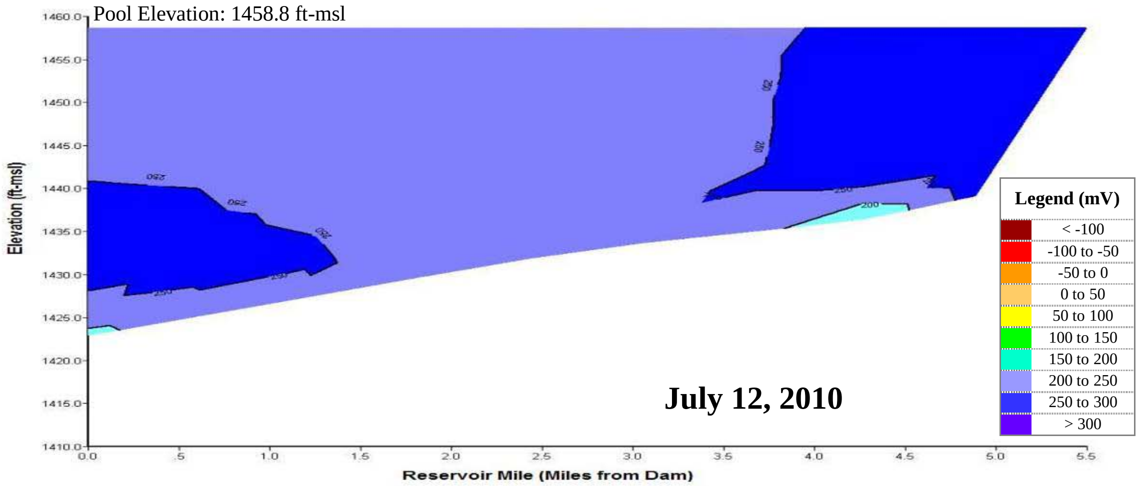
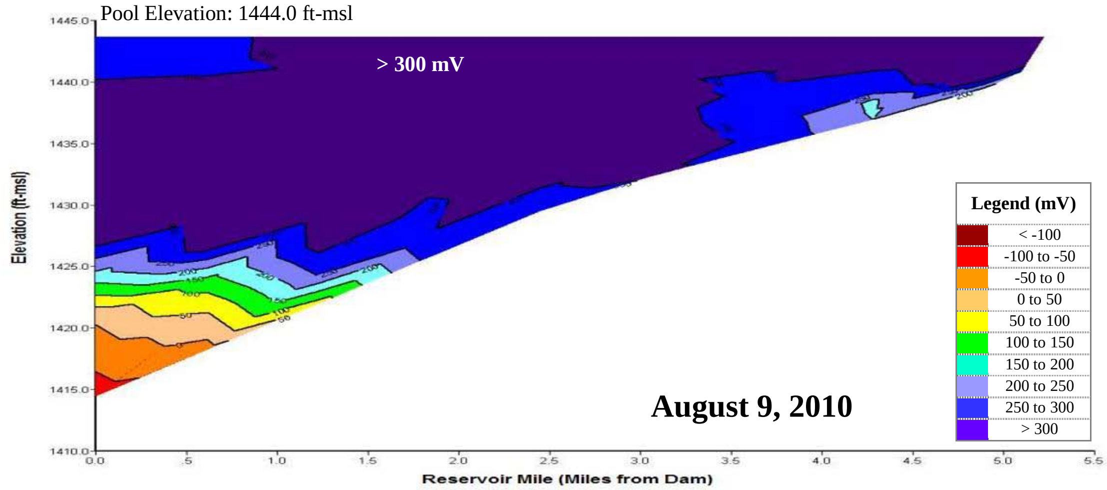


Plate 276. Longitudinal oxidation-reduction potential (mV) contour plots of Pipestem Reservoir based on depth-profile dissolved oxygen concentrations measured at sites PIPLKND1 and PIPLKML1 in 2010.



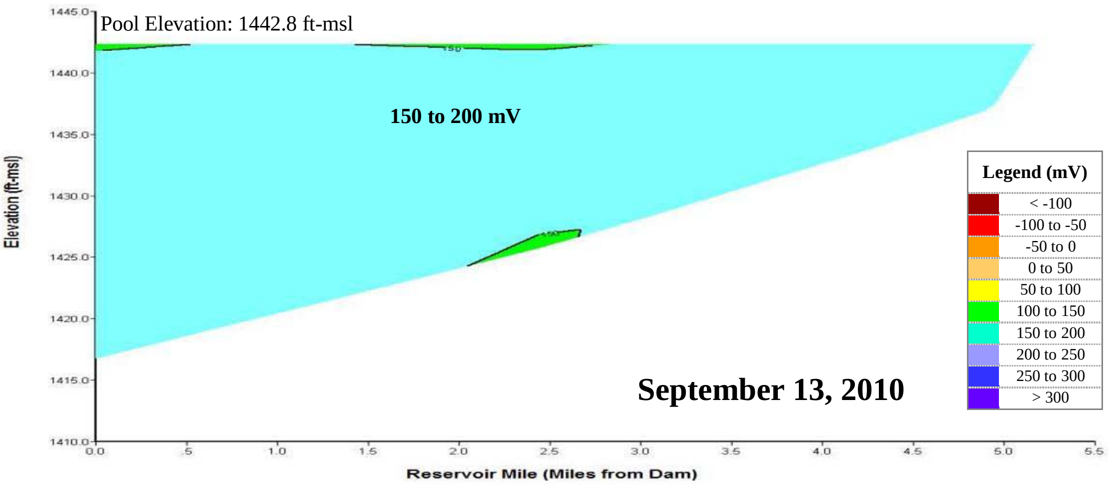


Plate 276. (Continued).

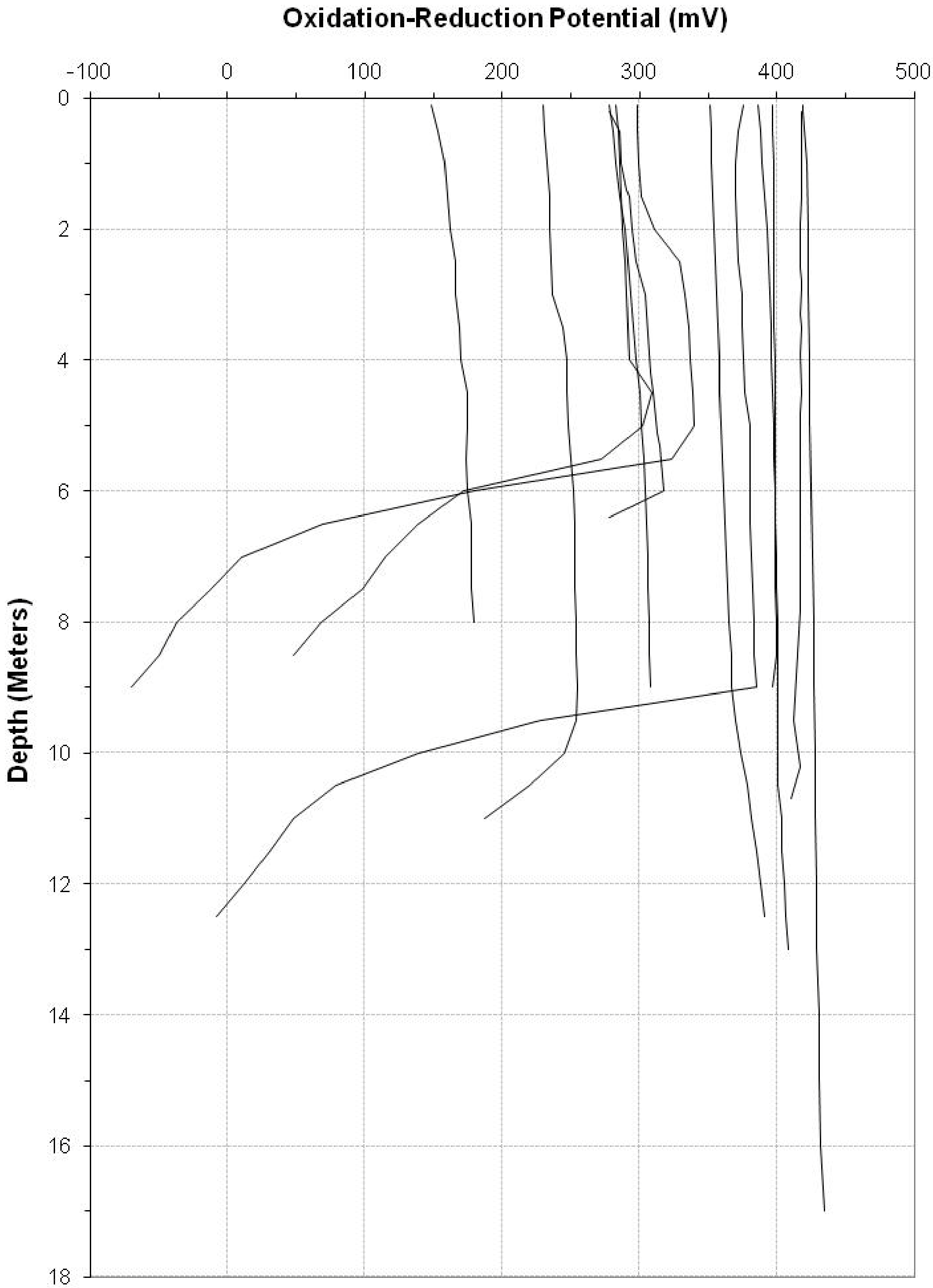


Plate 277. Oxidation-reduction potential depth profiles for Pipestem Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., PIPLKND1) during the summer over the 10-year period of 2001 through 2010.

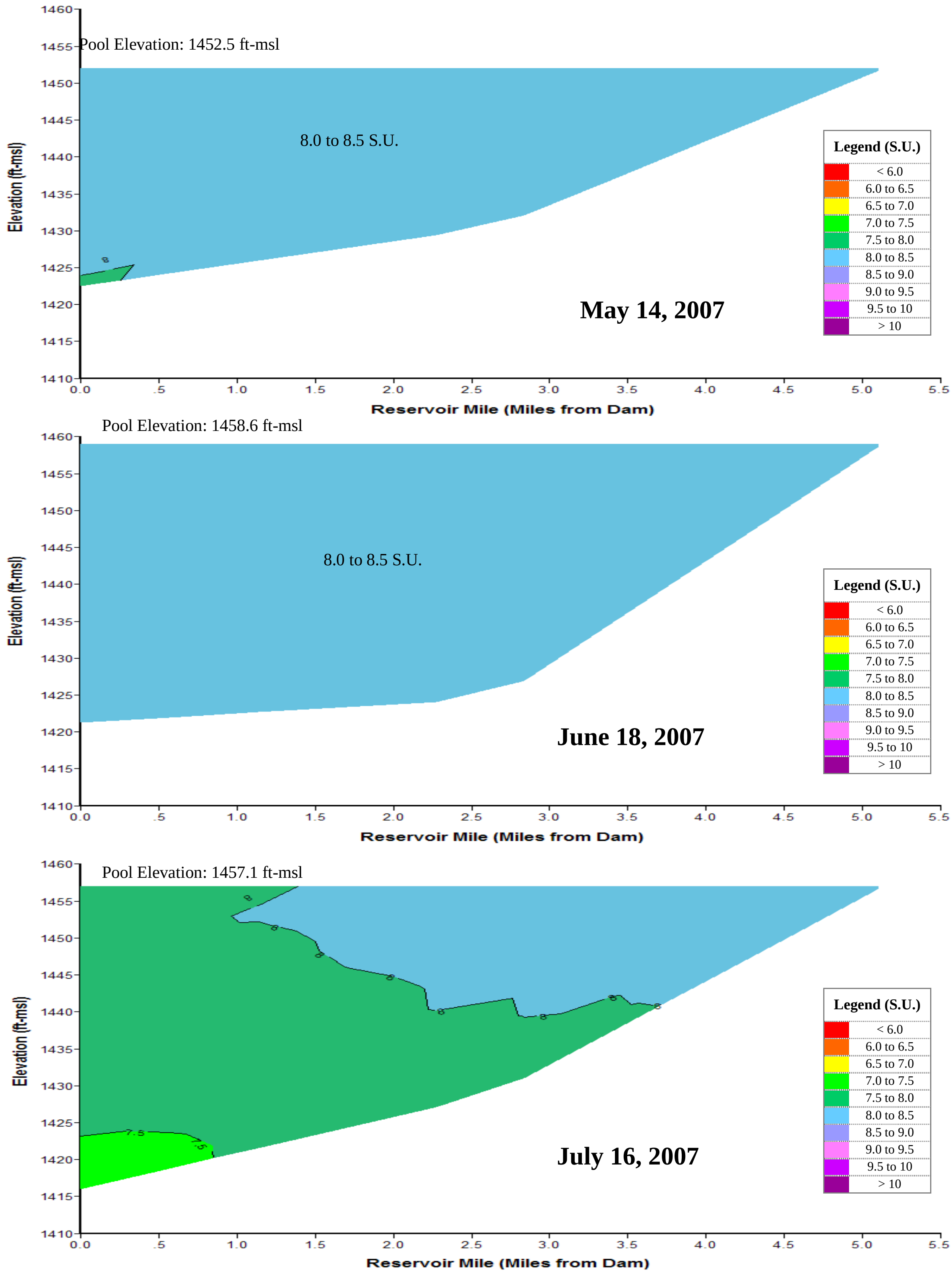
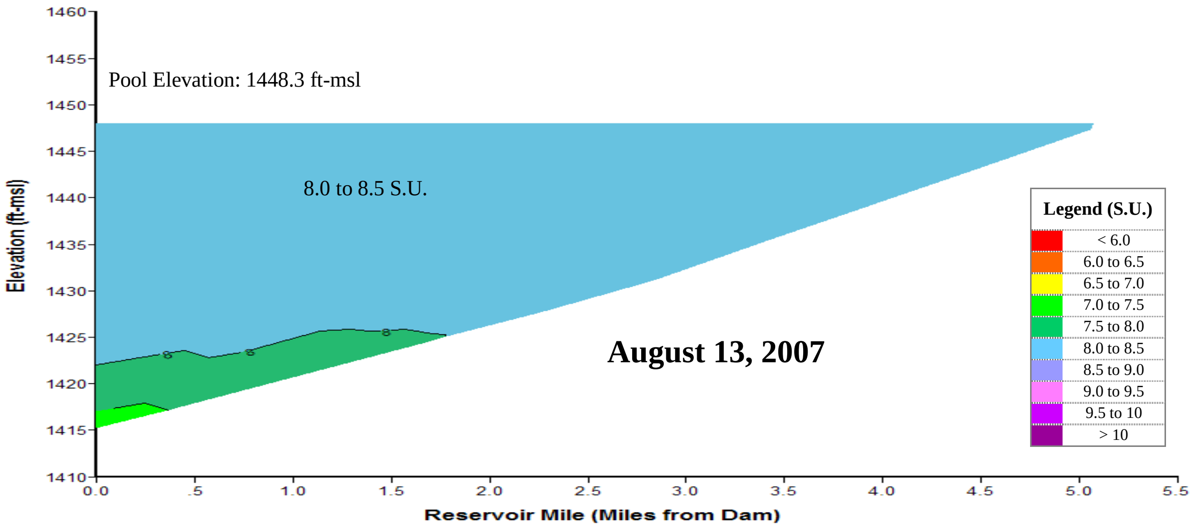


Plate 278. Longitudinal pH (S.U.) contour plots of Pipestem Reservoir based on depth-profile dissolved oxygen concentrations measured at sites PIPLKND1 and PIPLKML1 in 2007.



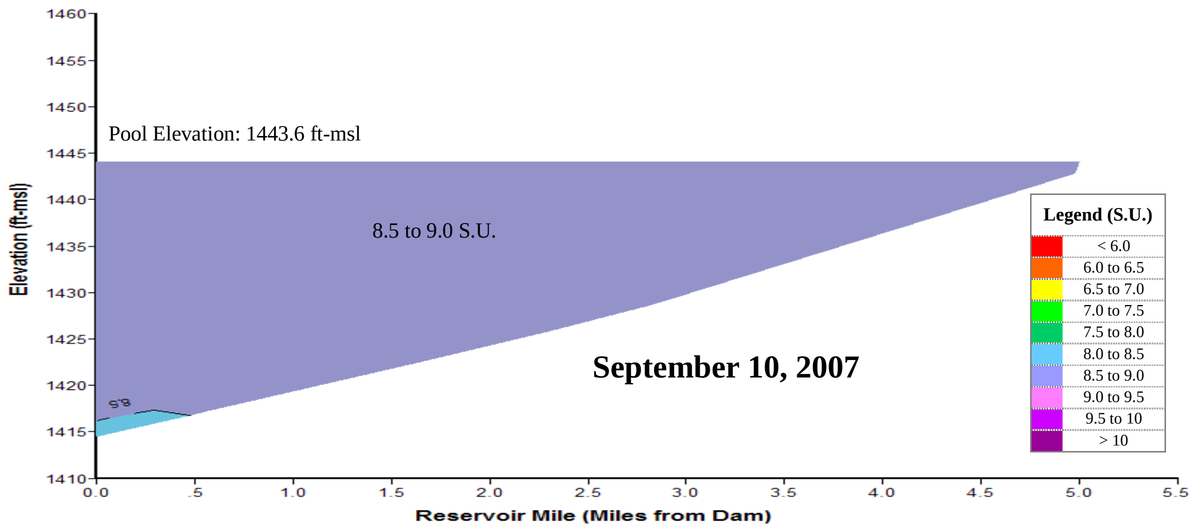


Plate 278. (Continued).

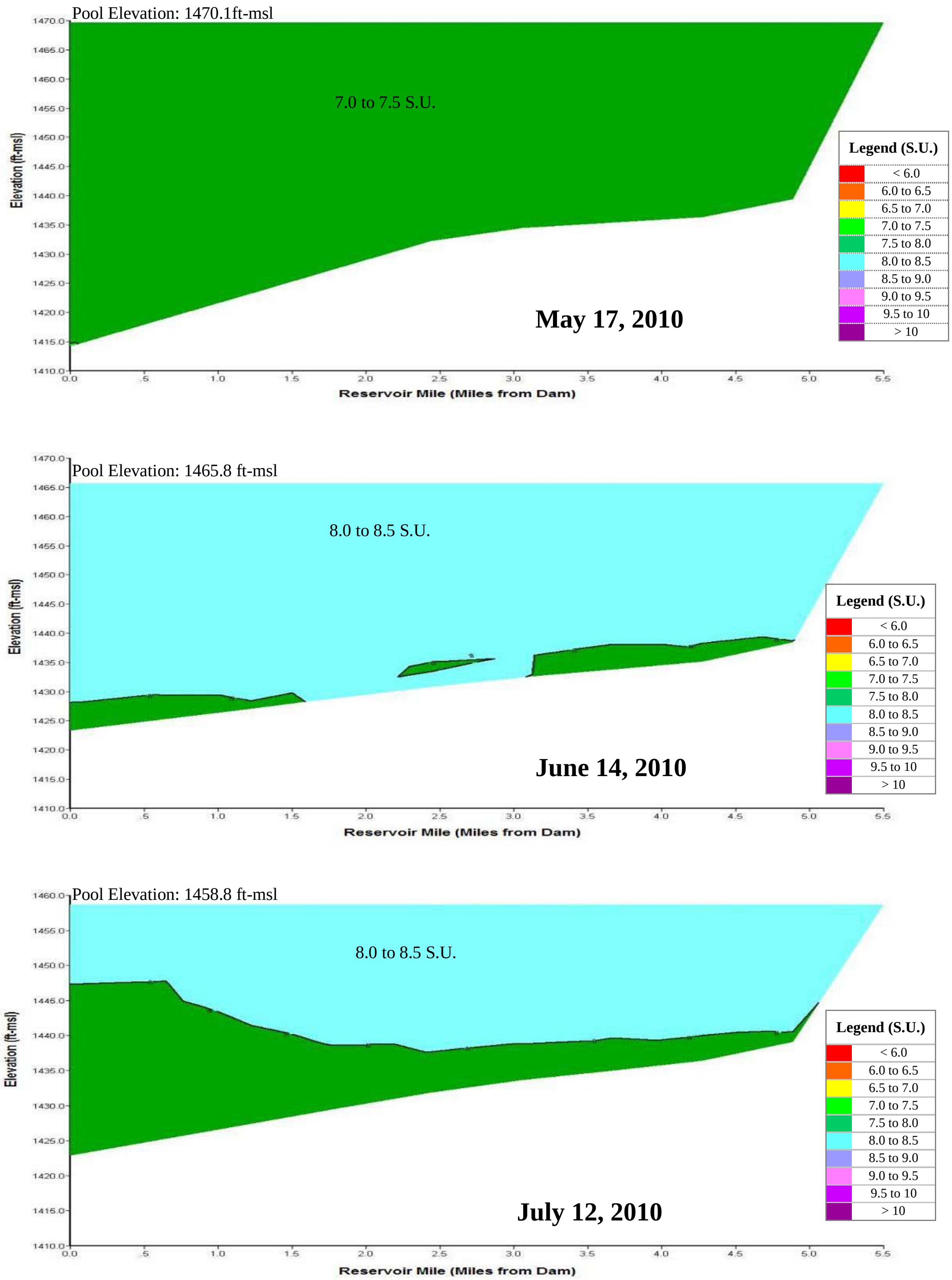
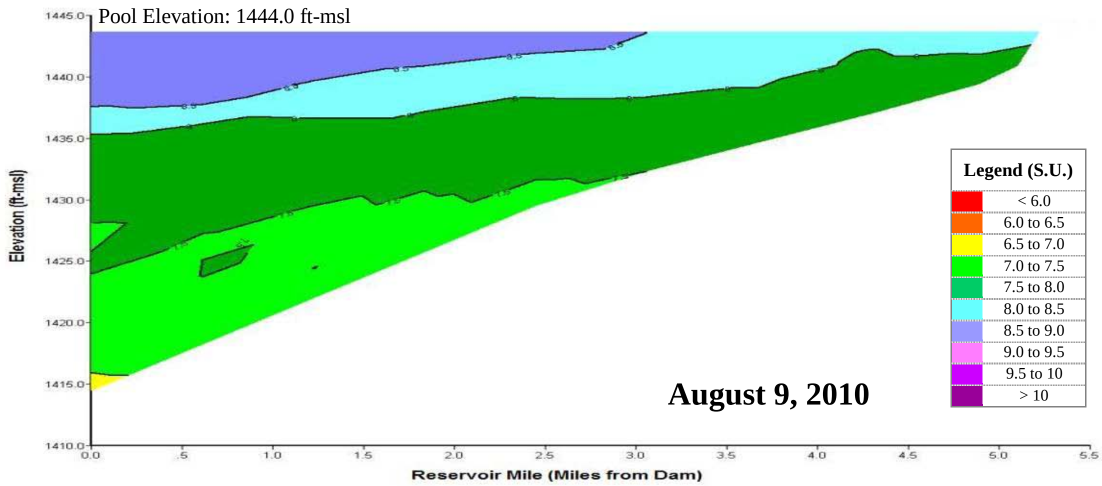


Plate 279. Longitudinal pH (S.U.) contour plots of Pipestem Reservoir based on depth-profile dissolved oxygen concentrations measured at sites PIPLKND1 and PIPLKML1 in 2010.



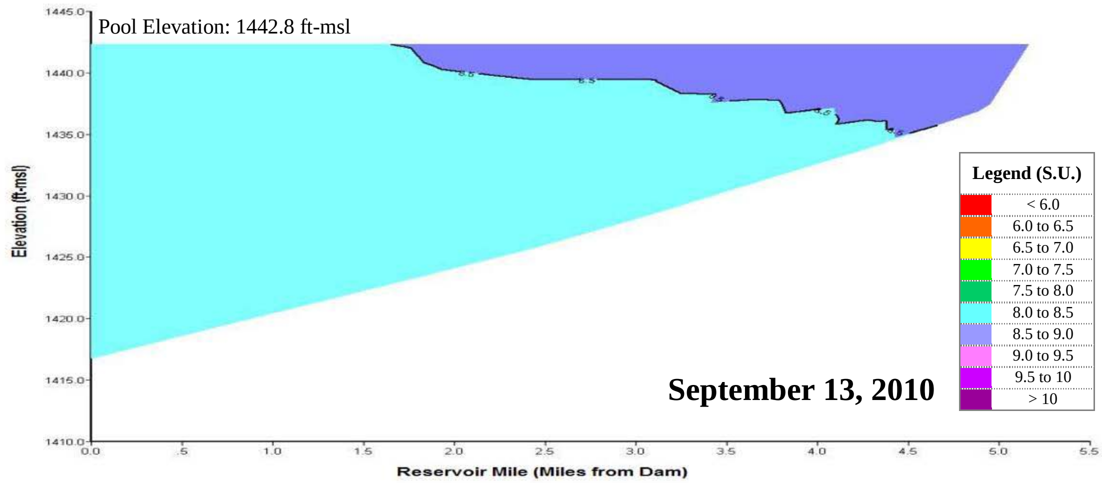


Plate 279. (Continued).

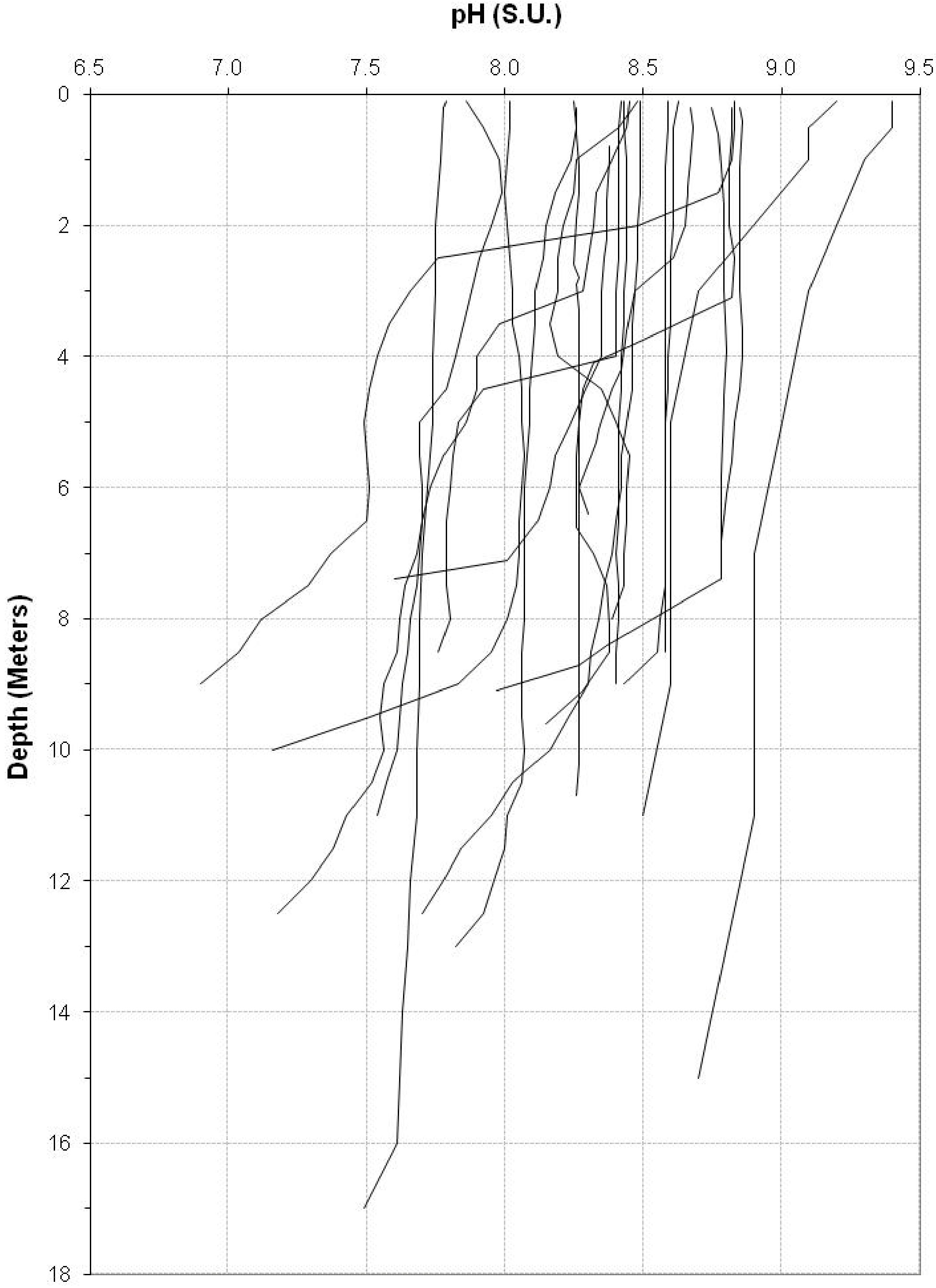


Plate 280. pH depth profiles for Pipestem Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., PIPLKND1) during the summer over the 10-year period of 2001 through 2010.

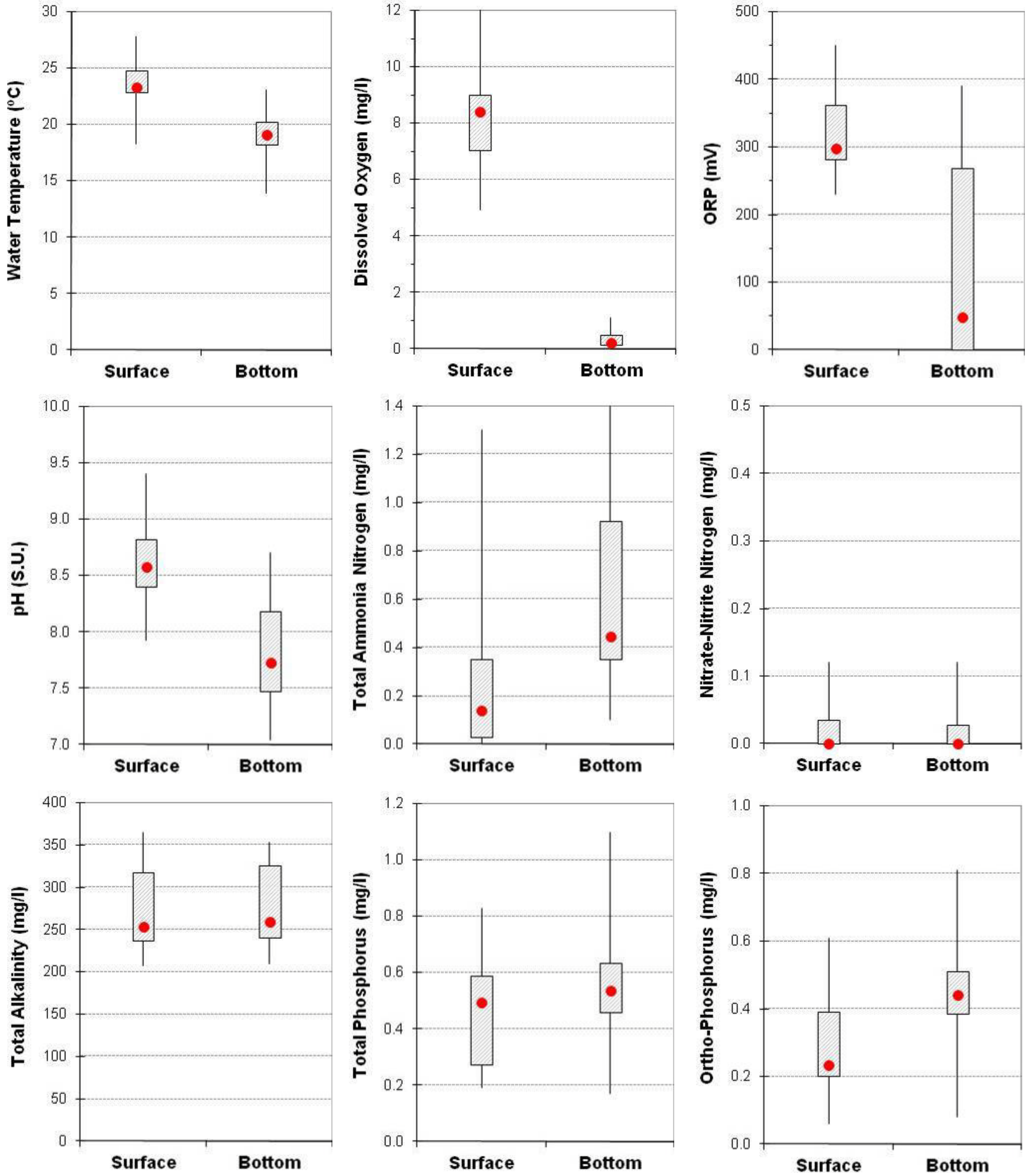


Plate 281. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), pH, alkalinity, total ammonia nitrogen, nitrate-nitrite nitrogen, total phosphorus, and ortho-phosphorus measured in Pipestem Reservoir when summer hypoxic conditions were present during the 10-year period 2001 through 2010. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot.)

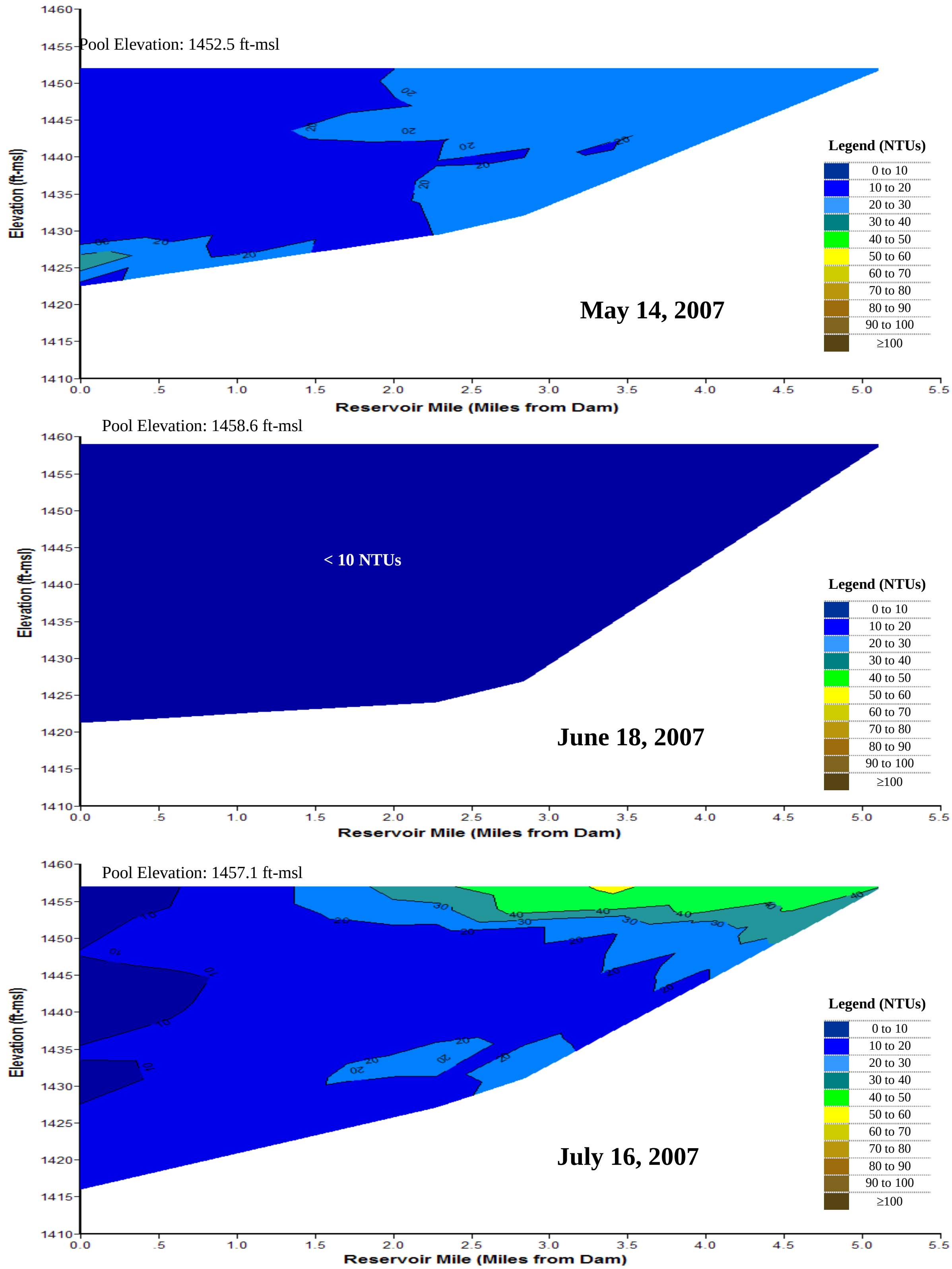
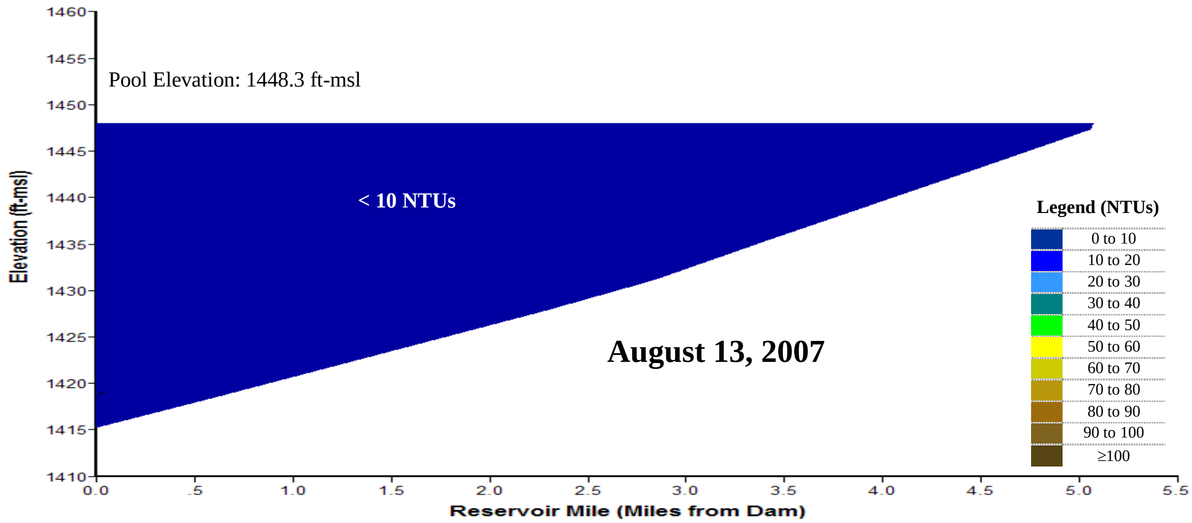


Plate 282. Longitudinal turbidity (NTU) contour plots of Pipestem Reservoir based on depth-profile dissolved oxygen concentrations measured at sites PIPLKND1 and PIPLKML1 in 2007.



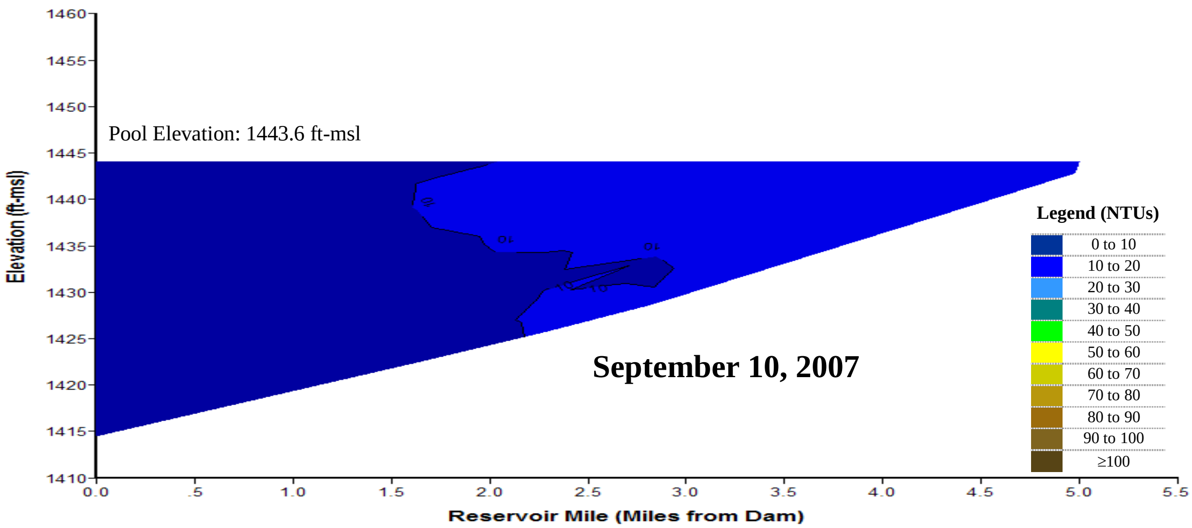


Plate 282. (Continued).

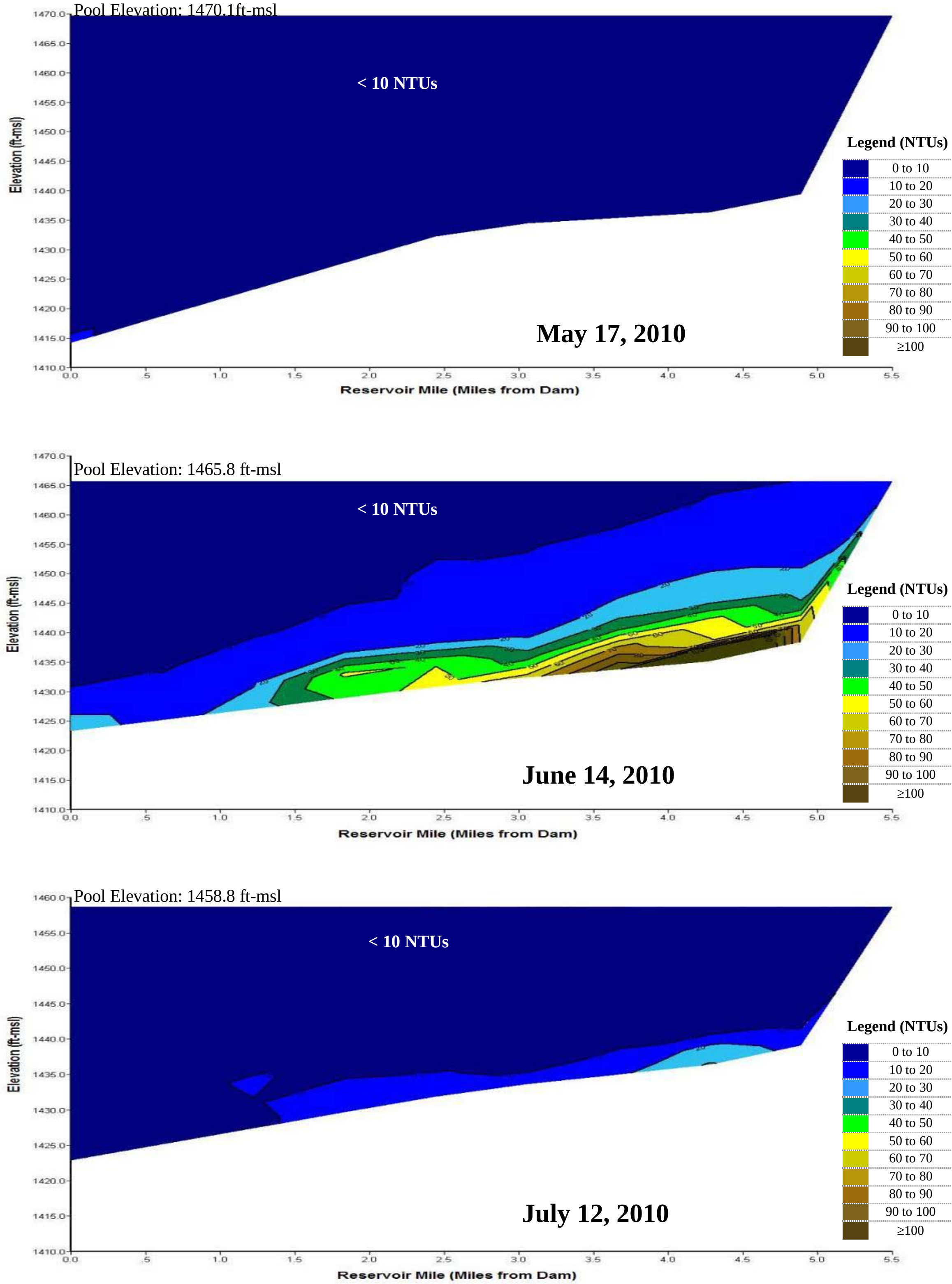
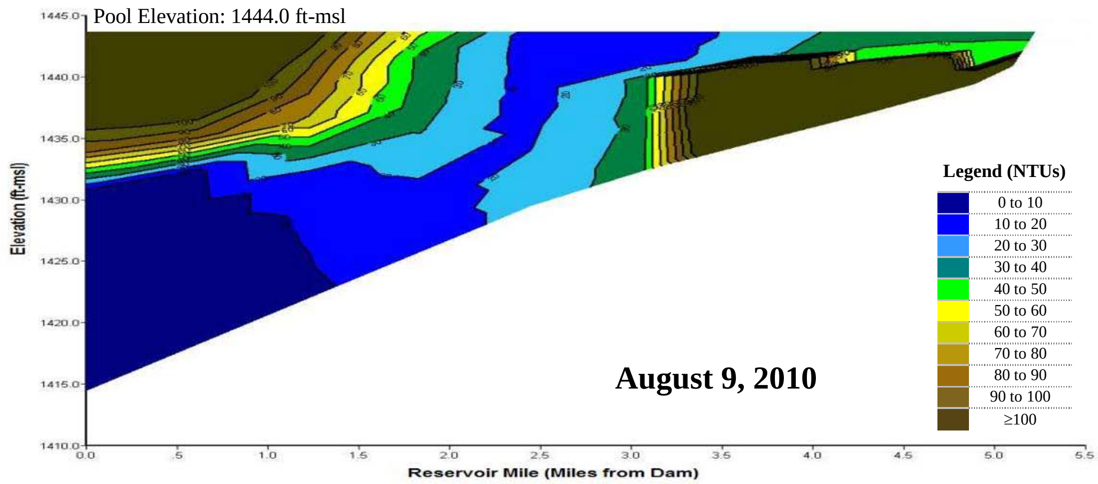


Plate 283. Longitudinal turbidity (NTU) contour plots of Pipestem Reservoir based on depth-profile dissolved oxygen concentrations measured at sites PIPLKND1 and PIPLKML1 in 2010.



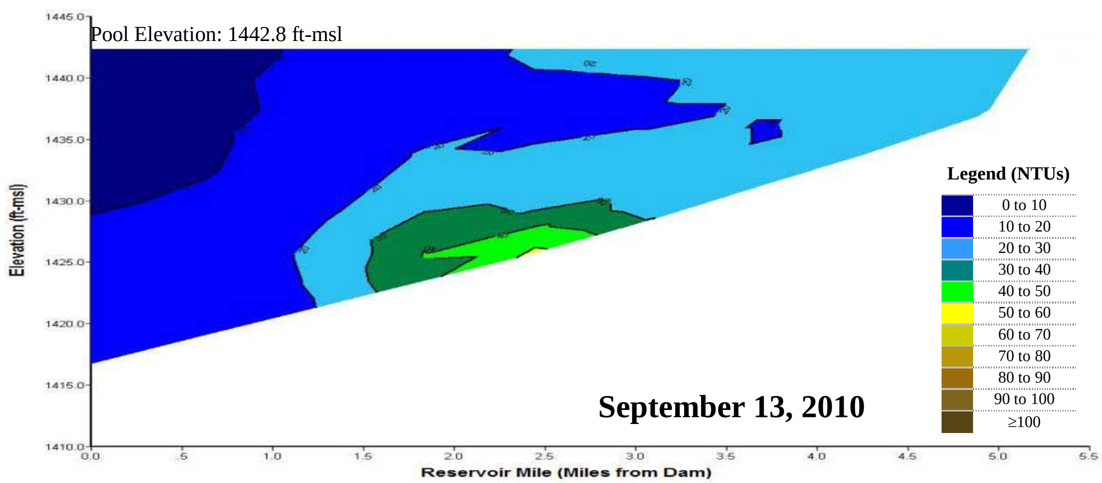


Plate 283. (Continued).

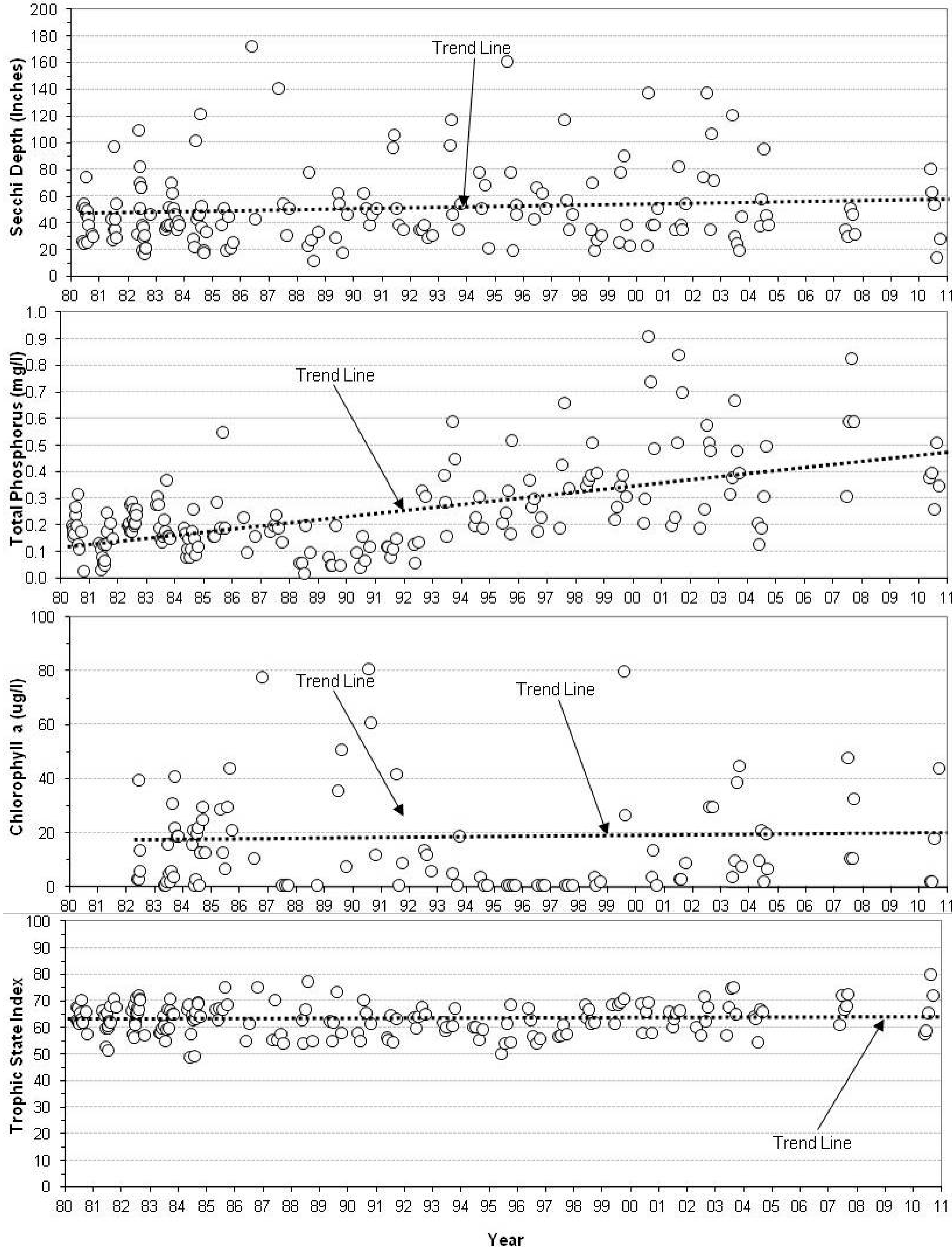


Plate 284. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Pipestem Reservoir at the near-dam, ambient site (i.e., site PIPLKND1) over the 31-year period of 1980 through 2010.

Plate 285. Summary of runoff water quality conditions monitored in Pipestem Creek upstream from Pipestem Reservoir at monitoring site PIPNF1 during 2001.

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedences	Percent WQS Exceedence
Water Temperature (°C)	0.1	5	20.1	18.8	10.8	29.1	29.4	0	0%
Dissolved Oxygen (mg/l)	0.1	5	8.8	8.2	6.1	11.3	≥ 5	0	0%
Dissolved Oxygen (% Sat.)	0.1	5	94.8	100.8	79.1	105.7	-----	-----	-----
Specific Conductance (umho/cm)	1	5	1203	1359	409	1530	-----	-----	-----
pH (S.U.)	0.1	4	8.1	8.2	6.5	9.3	≥7.0 & ≤9.0	1, 1	25%, 25%
Turbidity (NTUs)	1	5	26	30	15	35	-----	-----	-----
Alkalinity, Total (mg/l)	7	5	398	403	358	425	-----	-----	-----
Ammonia, Total (mg/l)	0.02	5	0.06	0.05	0.03	0.14	5.40 [1,2], 1.24[1,3]	0	0%
Carbon, Total Organic (mg/l)	0.05	5	20.00	21.00	16.00	23.00	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	5	1209	1148	1010	1641	-----	-----	-----
Hardness, Total (mg/l)	0.4	5	546.6	545.0	492.0	618.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	5	1.5	1.5	1.1	2.0	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	5	-----	0.03	n.d.	0.19	1.0	0	0%
Phosphorus, Total (mg/l)	0.02	5	0.51	0.50	0.24	0.75	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	5	0.42	0.37	0.25	0.63	-----	-----	-----
Sulfate, Total (mg/l)	1	3	361	371	323	390	250	3	100%
Suspended Solids, Total (mg/l)	4	5	48	48	29	70	-----	-----	-----
Arsenic, Total (ug/l)	3	3	10	12	5	13	340[2], 150[3], 10[4]	0, 0, 2	67%
Copper, Total (ug/l)	2	3	-----	n.d.	n.d.	n.d.	69[2], 40[3]	0	0%
Iron, Total (ug/l)	7	3	849	971	173	1403	-----	-----	-----
Lead, Total (ug/l)	2	3	-----	n.d.	n.d.	0	706[2], 28[3]	0	0%
Mercury, Total (ug/l)	0.02	1	-----	n.d.	n.d.	n.d.	1.7[2], 0.012[3], 0.05[4]	0	0%
Manganese, Total (ug/l)	2	3	612	370	173	1294	-----	-----	-----
Zinc, Total (ug/l)	3	3	-----	5	n.d.	11	504[2,3]	0	0%
Pesticide Scan (ug/l)[C]	0.05	2	-----	n.d.	n.d.	1.30	-----	-----	-----

n.d. = Not detected.

[A] Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

[B] [1] Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.

[2] Acute criterion for aquatic life.

[3] Chronic criterion for aquatic life.

Note: North Dakota's chronic WQS criterion for Mercury was below the detection limit during the reporting period.

[4] Human health criterion for surface waters.

Note: North Dakota's WQS criteria for metals are based on total recoverable; some analyzed metal concentrations were dissolved. Listed criteria are given for comparison and were calculated using the median hardness.

[C] The pesticide scan (GCMS) includes: acetochlor, alachlor, atrazine, benfluralin, butylate, chlorpyrifos, cyanazine, cycloate, EPTC, hexazinone, isopropalin, metolachlor, metribuzin, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, profluralin, prometon, propachlor, propazine, simazine, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

Plate 286. Summary of water quality conditions monitored in Cold Brook Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site CODLKND1) from May to September during the 10-year period 2001 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, and ORP are for water column profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at ½ the measured Secchi depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	14	3582.6	3582.7	3582.0	3583.6	-----	-----	-----
Water Temperature (°C)	0.1	271	19.6	20.7	10.3	26.0	18.3(1), 23.9(2), 26.6(3)	188, 53, 0	66%, 20%, 0%
Dissolved Oxygen (mg/l)	0.1	271	9.3	9.6	0.2	15.2	≥6, ≥7	11, 16	4%, 6%
Dissolved Oxygen (% Sat.)	0.1	271	108.0	107.2	2.2	177.3	-----	-----	-----
Specific Conductance (umho/cm)	1	271	485	477	389	746	-----	-----	-----
pH (S.U.)	0.1	271	8.2	8.3	7.1	8.5	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	1	123	-----	0	n.d.	5	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	119	326	319	69	441	-----	-----	-----
Secchi Depth (in.)	1	14	230	222	110	374	-----	-----	-----
Alkalinity, Total (mg/l)	7	24	165	162	141	190	-----	-----	-----
Ammonia, Total (mg/l)	0.02	17	-----	0.05	n.d.	1.00	3.15 (4,5), 0.98 (4,6)	0, 1	0%, 6%
Chlorophyll *a* (ug/l) – Field Probe	1	78	4	4	1	9			
Chlorophyll *a* (ug/l) – Lab Determined	1	9	3	2	1	7	-----	-----	-----
Hardness, Total (mg/l)	0.4	11	239.8	234.0	215.0	301.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	25	-----	0.2	n.d.	1.3	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	25	-----	n.d.	n.d.	0.07	10(8)	0	0%
Phosphorus, Total (mg/l)	0.02	25	0.06	0.02	n.d.	0.73	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	25	-----	n.d.	n.d.	0.02	-----	-----	-----
Suspended Solids, Total (mg/l)	4	25	-----	n.d.	n.d.	9	53(5), 30(6)	0	0%
Antimony, Dissolved (ug/l)	6	2	-----	n.d.	n.d.	n.d.	6(7)	0	0%
Arsenic, Dissolved (ug/l)	3	3	5	6	3	7	340(5), 150(6), 0.018(7)	0, 0, 4	0%, 0%, 100%
Beryllium, Dissolved (ug/l)	0.5	2	-----	n.d.	n.d.	n.d.	4(7)	0	0%
Cadmium, Dissolved (ug/l)	0.5	2	-----	n.d.	n.d.	n.d.	9.3(5), 1.9(6)	0	0%
Chromium, Dissolved (ug/l)	2	2	-----	n.d.	n.d.	n.d.	1,101(5), 357(6)	0	0%
Copper, Dissolved (ug/l)	2	3	-----	n.d.	n.d.	n.d.	38(5), 23(6), 1,300(7)	0	0%
Lead, Dissolved (ug/l)	2	2	-----	n.d.	n.d.	n.d.	160(5), 6.3(6)	0	0%
Mercury, Dissolved (ug/l)	0.02	2	-----	n.d.	n.d.	n.d.	1.4(5)	0	0%
Mercury, Total (ug/l)	0.02	1	-----	n.d.	n.d.	n.d.	0.012(6)	b.d.	b.d.
Nickel, Dissolved (ug/l)	3	2	-----	n.d.	n.d.	n.d.	2,906 (5), 323(6)	0	0%
Silver, Dissolved (ug/l)	1	2	-----	n.d.	n.d.	n.d.	15(5)	0	0%
Zinc, Dissolved (ug/l)	3	1	-----	n.d.	n.d.	n.d.	235(5), 215(6),7,400(7)	0	0%
Microcystin (ug/l)	0.2	4	-----	n.d.	n.d.	0.5	-----	-----	-----
Alachlor, Total (ug/l)(C)	0.05	5	-----	n.d.	n.d.	0.08	-----	-----	-----
Atrazine, Total (ug/l)(C)	0.05	5	-----	n.d.	n.d.	0.12	-----	-----	-----
Metolachlor, Total (ug/l)(C)	0.05	5	-----	n.d.	n.d.	0.07	-----	-----	-----
Pesticide Scan (ug/l)(D)	0.05	2	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected., b.d. = Below detection limit

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) Water temperature criterion for protection of coldwater permanent fish life propagation.
(2) Water temperature criterion for protection of coldwater marginal fish life propagation.
(3) Water temperature criterion for protection of warmwater permanent fish life propagation.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values of 8.3 and 21.1 respectively.
(5) Acute criterion for aquatic life.
(6) Chronic criterion for aquatic life.
(7) Human health criterion for surface waters.
(8) Daily maximum criterion for domestic water supply.
Note: North Dakota's WQS criteria for metals are based on total recoverable, most analyzed metal concentrations were dissolved. Listed criteria are given for comparison and were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, atrazine, benfluralin, butylate, chlorpyrifos, cyanazine, cycloate, EPTC, hexazinone, isopropalin, metribuzin, metolachlor, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, profluralin, prometon, propachlor, propazine, simazine, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

Plate 287. Summary of water quality conditions monitored in Cold Brook Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site CODLKML1) from May to September during the 7-year period 2002 through 2008. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* are for water column profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	12	3582.7	3582.7	3582.0	3583.6	-----	-----	-----
Secchi Depth (in.)	1	11	186	168	120	263	-----	-----	-----
Water Temperature (°C)	0.1	160	20.3	20.5	14.1	25.8	18.3(1), 23.9(2), 26.6(3)	119, 34, 0	74%, 21%, 0%
Dissolved Oxygen (mg/l)	0.1	160	9.3	9.1	6.6	14.9	≥6, ≥7	0, 4	0%, 3%
Dissolved Oxygen (% Sat.)	0.1	160	110.8	108.1	72.7	194.1	-----	-----	-----
Specific Conductance (umho/cm)	1	160	478	478	443	530	-----	-----	-----
pH (S.U.)	0.1	160	8.3	8.3	8.1	8.5	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	1	85	-----	n.d.	n.d.	3	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	86	330	326	248	419	-----	-----	-----
Chlorophyll *a* (ug/l)	1	52	3	2	n.d.	7	-----	-----	-----

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) Water temperature criterion for protection of coldwater permanent fish life propagation.
(2) Water temperature criterion for protection of coldwater marginal fish life propagation.
(3) Water temperature criterion for protection of warmwater permanent fish life propagation.

Plate 288. Summary of water quality conditions monitored in Cold Brook Reservoir at the up-lake, deepwater ambient monitoring location (i.e., site CODLKUP1) from May to September during 2008. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* are for water column profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	4	3582.3	3582.3	3582.0	3582.5	-----	-----	-----
Secchi Depth (in.)	1	4	124	108	98	181	-----	-----	-----
Water Temperature (°C)	0.1	30	21.6	21.6	14.3	25.3	18.3(1), 23.9(2), 26.6(3)	27, 9, 0	90%, 30%, 0%
Dissolved Oxygen (mg/l)	0.1	30	9.5	9.6	6.9	10.4	≥6, ≥7	0, 1	0%, 3%
Dissolved Oxygen (% Sat.)	0.1	30	112.2	111.3	84.3	129.4	-----	-----	-----
Specific Conductance (umho/cm)	1	30	470	460	451	501	-----	-----	-----
pH (S.U.)	0.1	30	8.4	8.4	7.6	8.5	≥6.5 & ≤9.0	0	0%
Turbidity (NTUs)	1	30	-----	n.d.	n.d.	3	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	30	308	300	280	333	-----	-----	-----
Chlorophyll *a* (ug/l)	1	30	4	3	n.d.	17	-----	-----	-----

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) Water temperature criterion for protection of coldwater permanent fish life propagation.
(2) Water temperature criterion for protection of coldwater marginal fish life propagation.
(3) Water temperature criterion for protection of warmwater permanent fish life propagation.

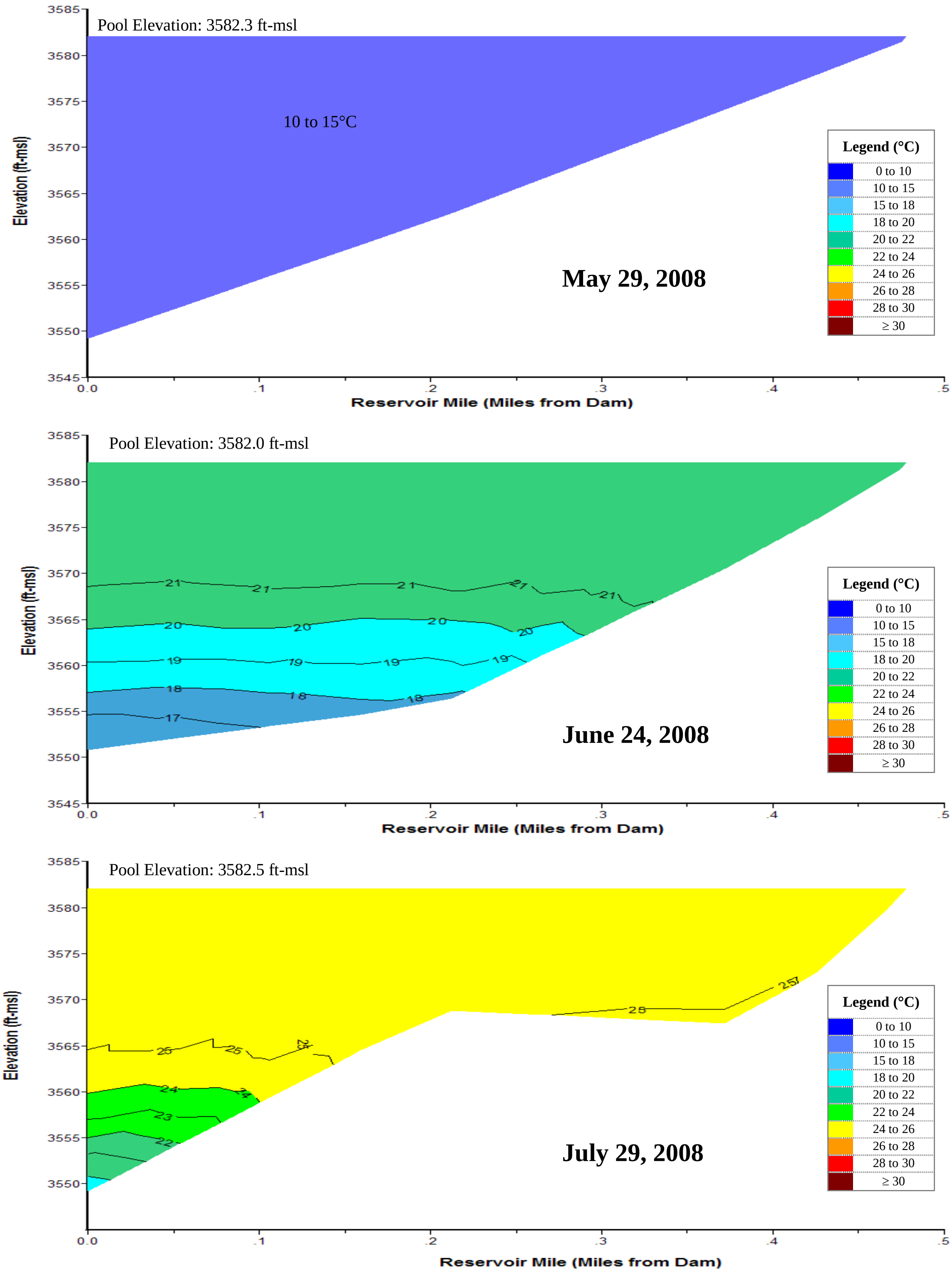


Plate 289. Longitudinal water temperature (°C) contour plots of Cold Brook Reservoir based on depth-profile water temperatures measured at sites CODLKND1, CODLKML1, and CODLKUP1 in 2008.

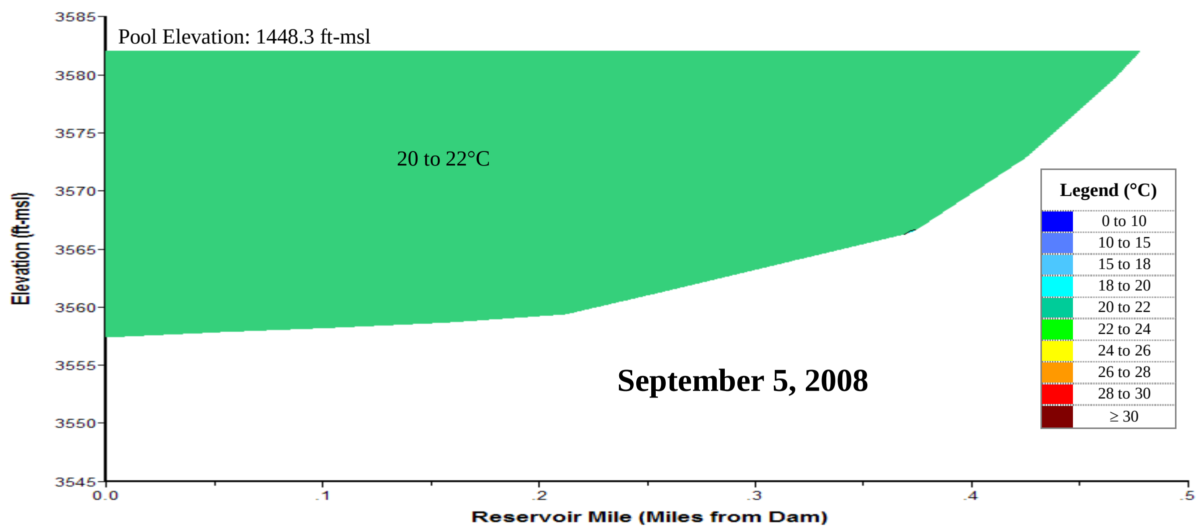


Plate 289. (Continued).

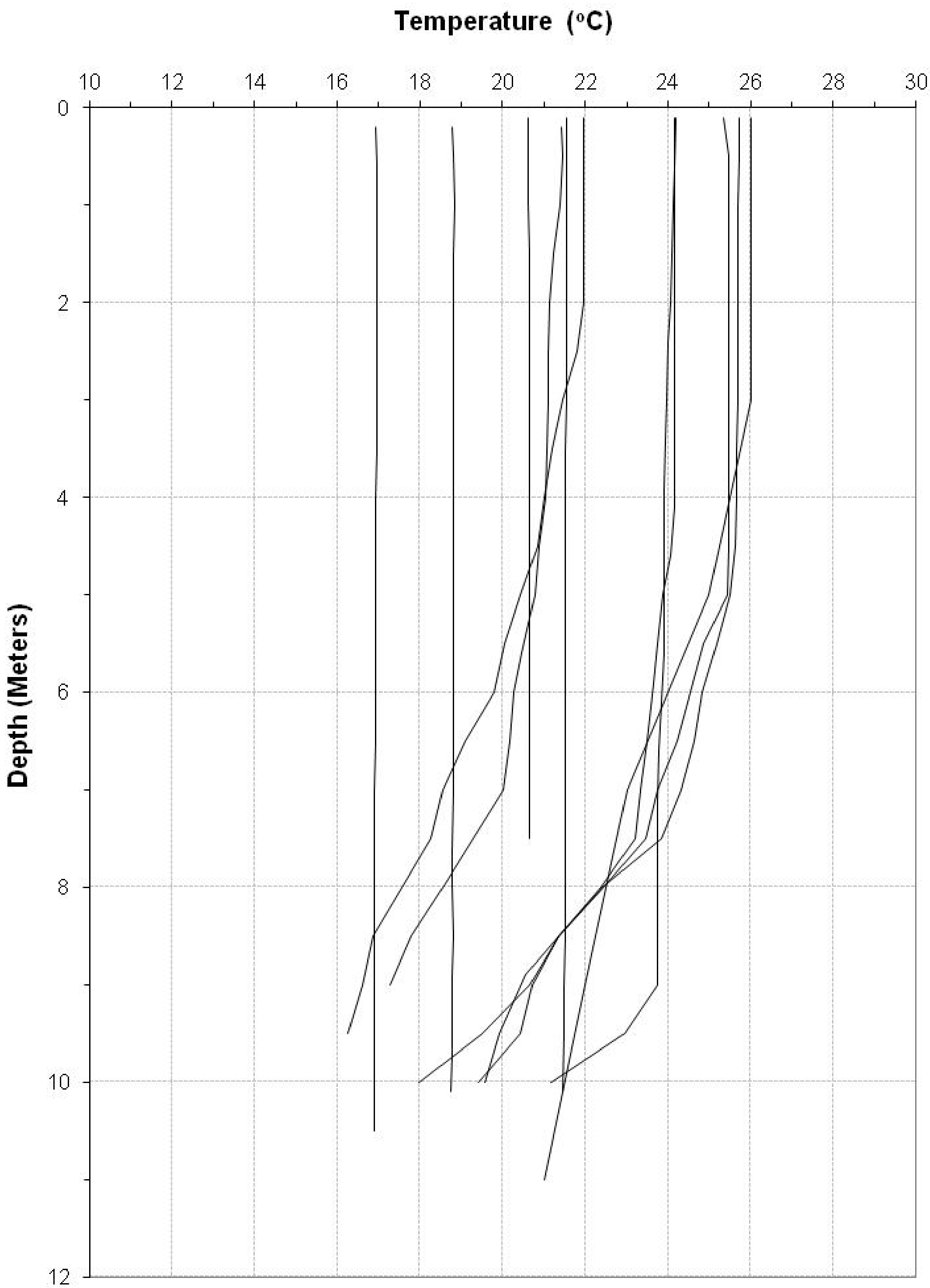


Plate 290. Temperature depth profiles for Cold Brook Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., CODLKND1) during the summer over the 10-year period of 2001 through 2010.

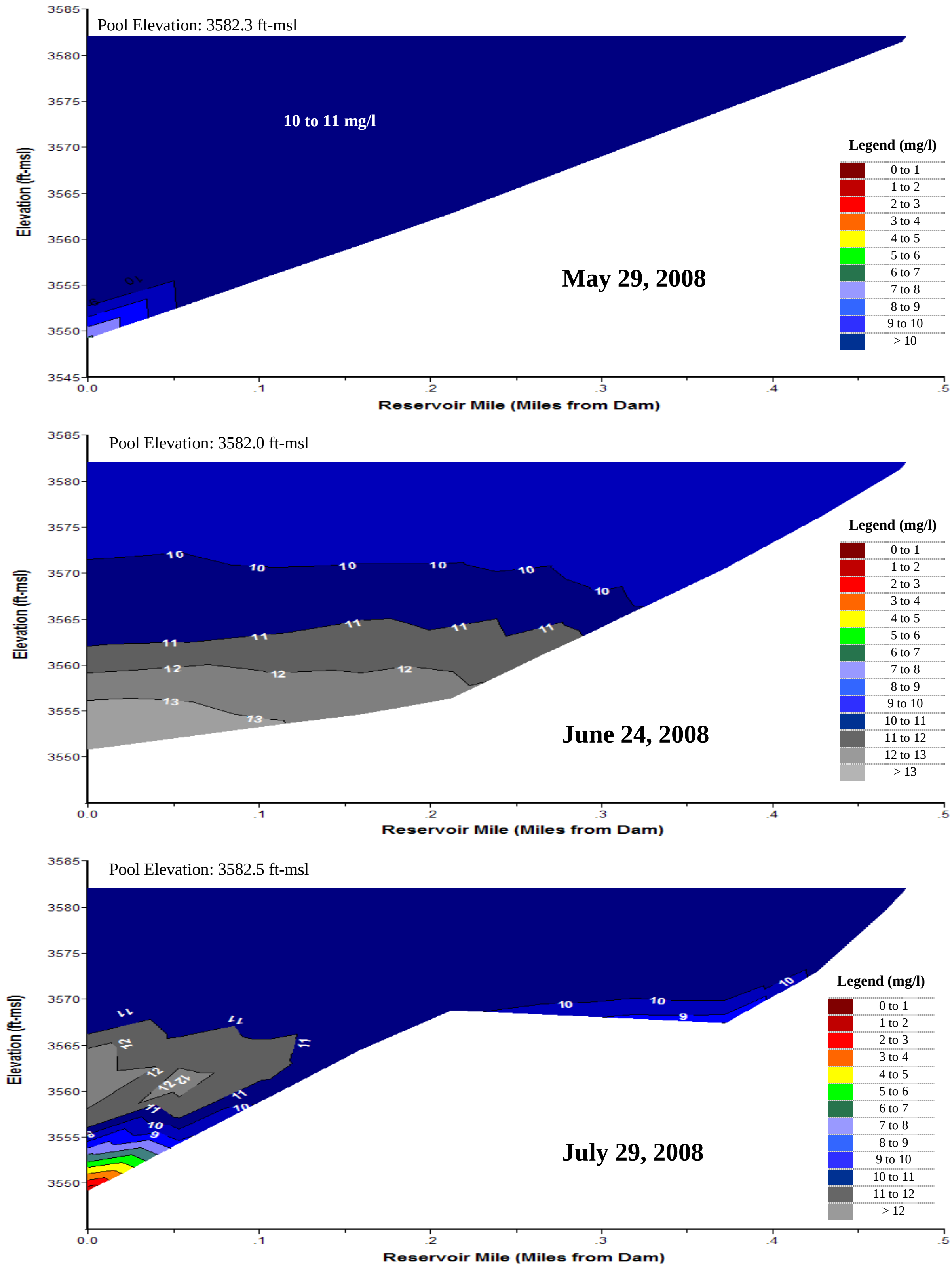


Plate 291. Longitudinal dissolved oxygen (mg/l) contour plots of Cold Brook Reservoir based on depth-profile dissolved oxygen concentrations measured at sites CODLKND1, CODLKML1, and CODLKUP1 in 2008.

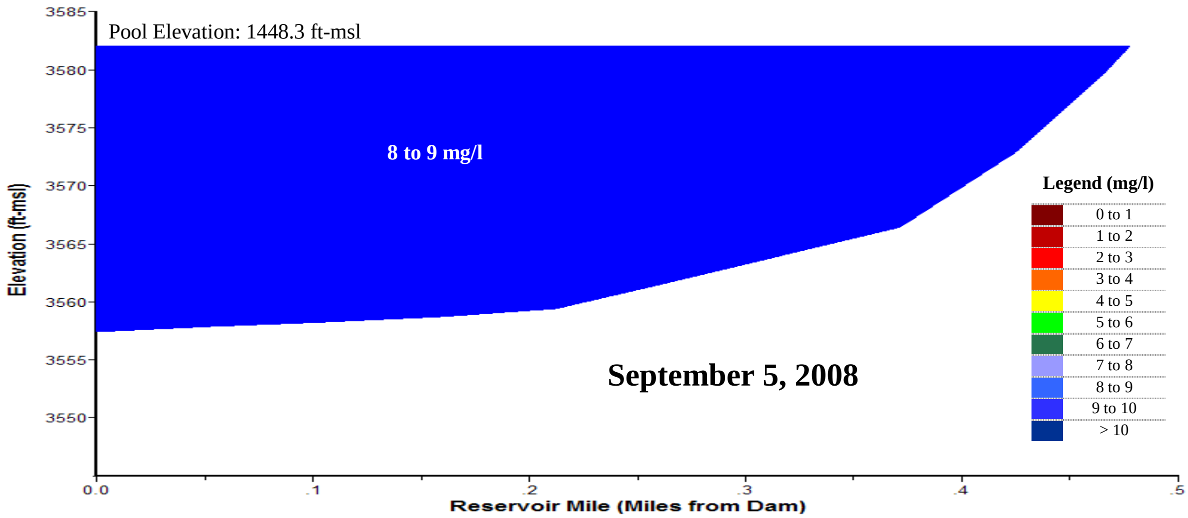


Plate 291. (Continued).

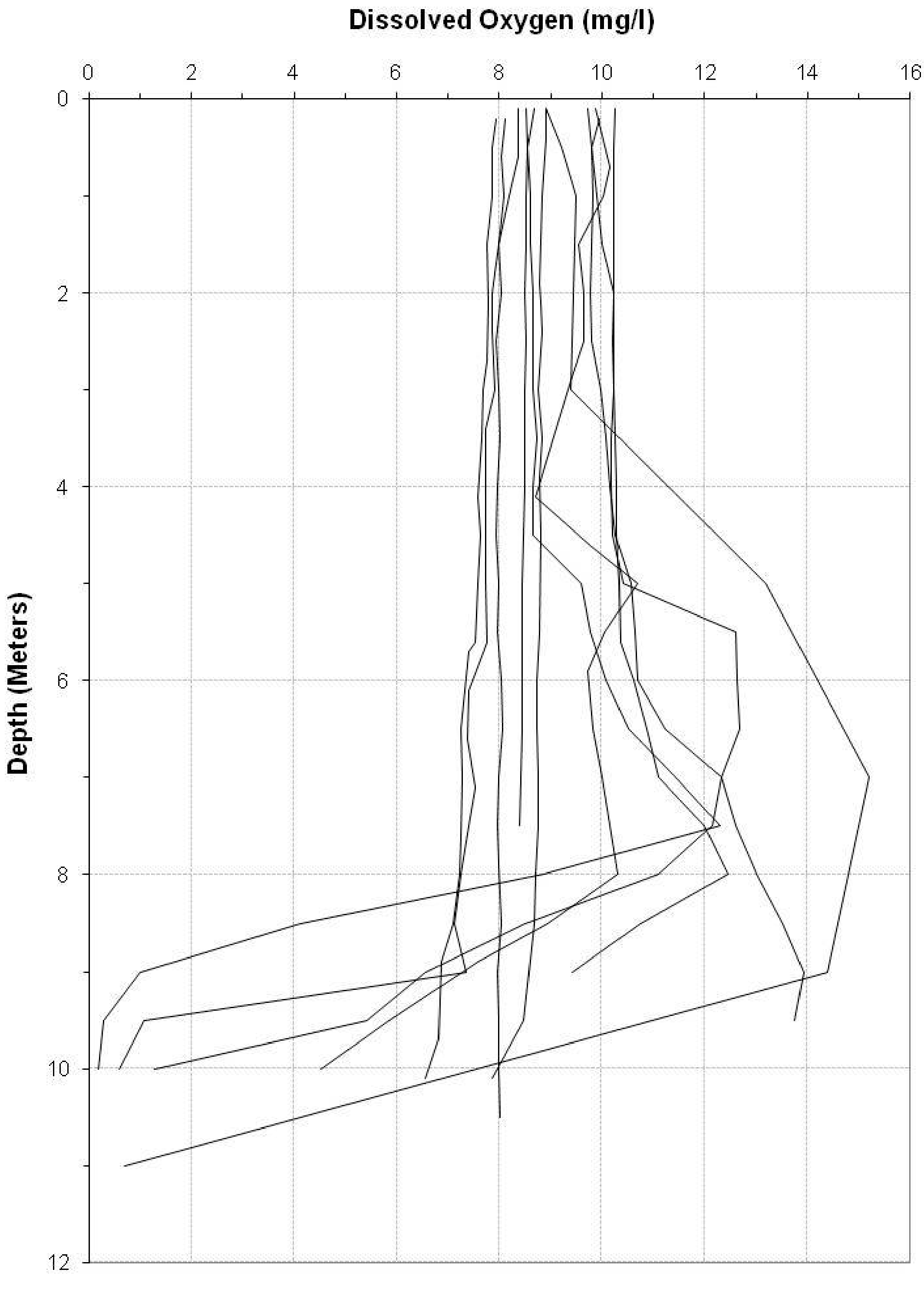


Plate 292. Dissolved oxygen depth profiles for Cold Brook Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., CODLKND1) during the summer over the 10-year period of 2001 through 2010.

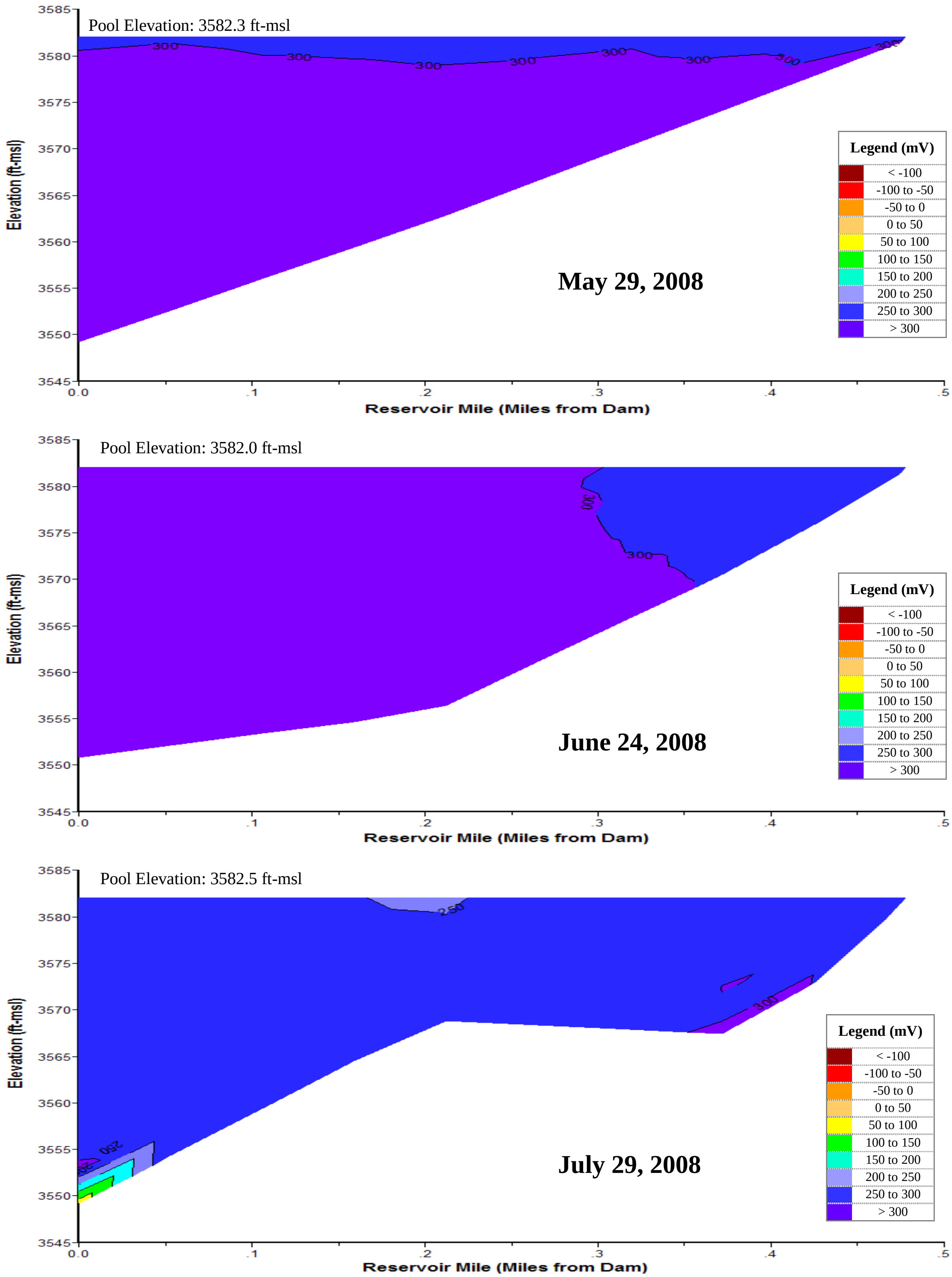


Plate 293. Longitudinal oxidation-reduction potential (mV) contour plots of Cold Brook Reservoir based on depth-profile ORP levels measured at sites CODLKND1, CODLKML1, and CODLKUP1 in 2008.

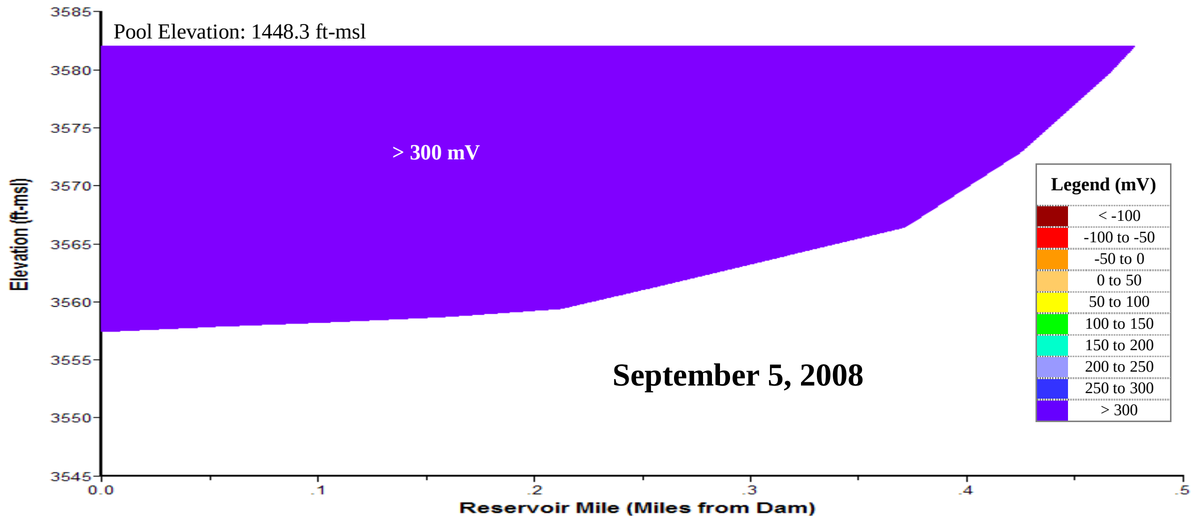


Plate 293. (Continued).

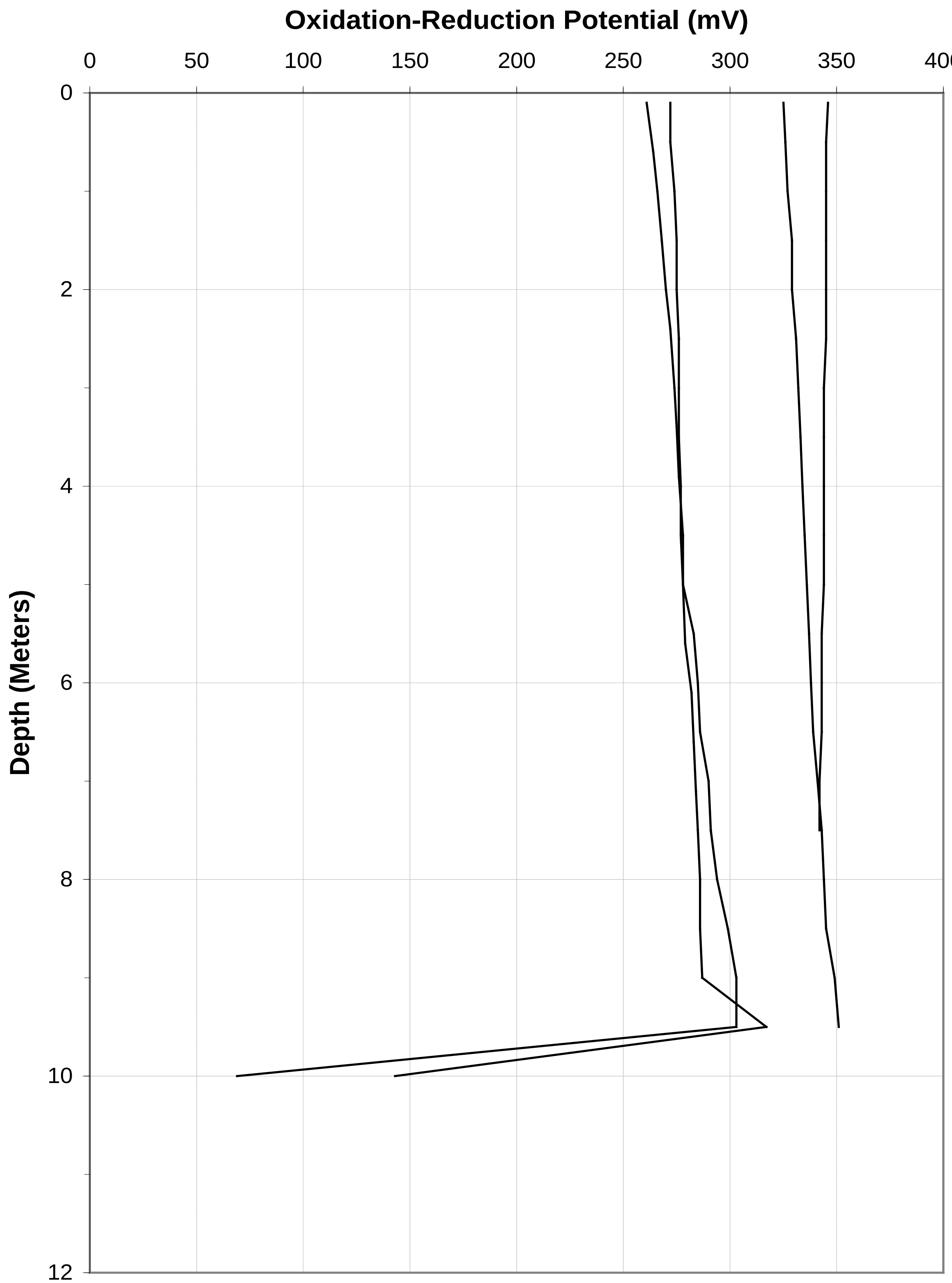


Plate 294. Oxidation-reduction potential depth profiles for Cold Brook Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., CODLKND1) during the summer over the 8-year period of 2003 through 2010.

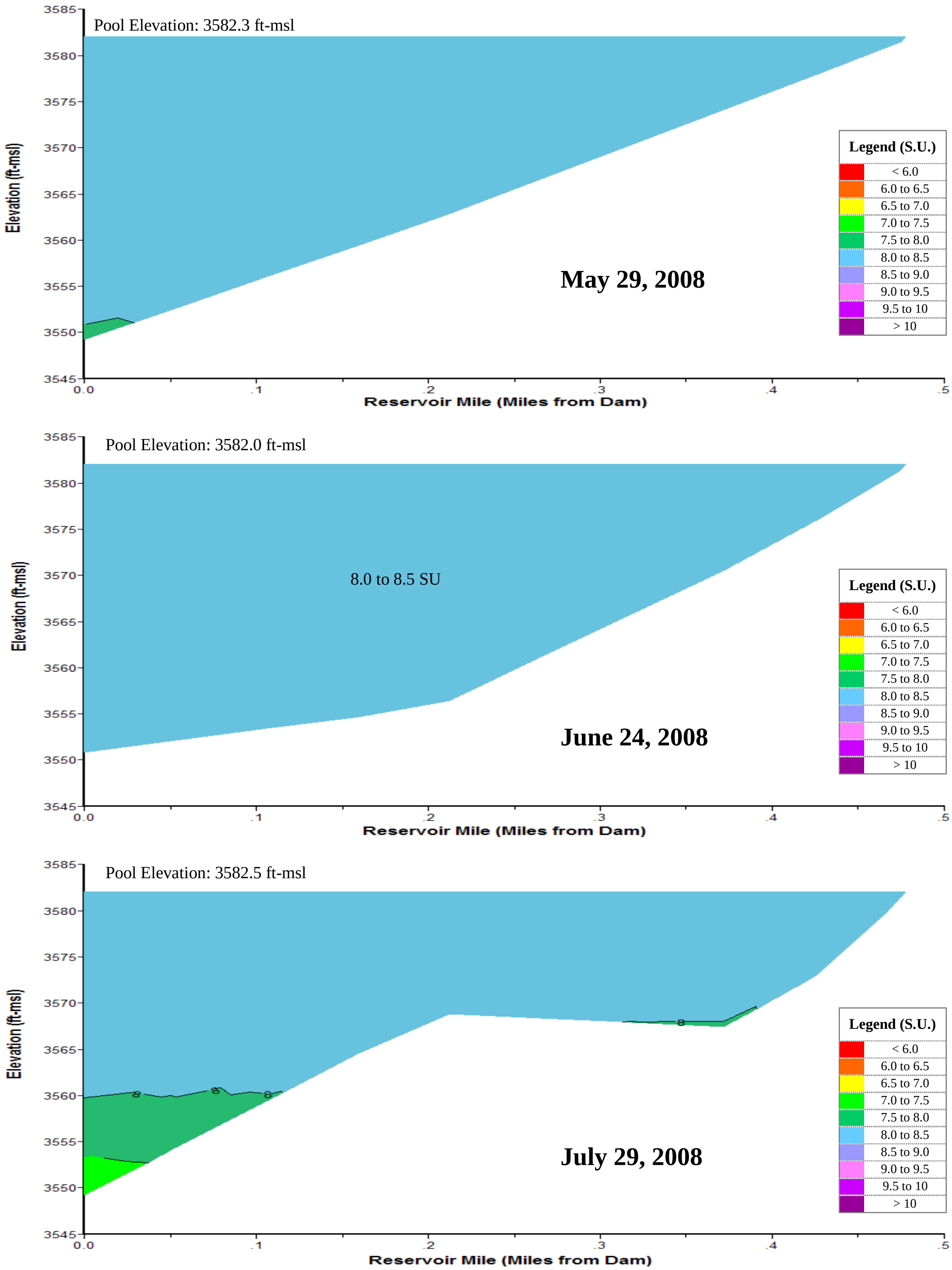


Plate 295. Longitudinal pH (S.U.) contour plots of Cold Brook Reservoir based on depth-profile pH levels measured at sites CODLKND1, CODLKML1, and CODLKUP1 in 2008.

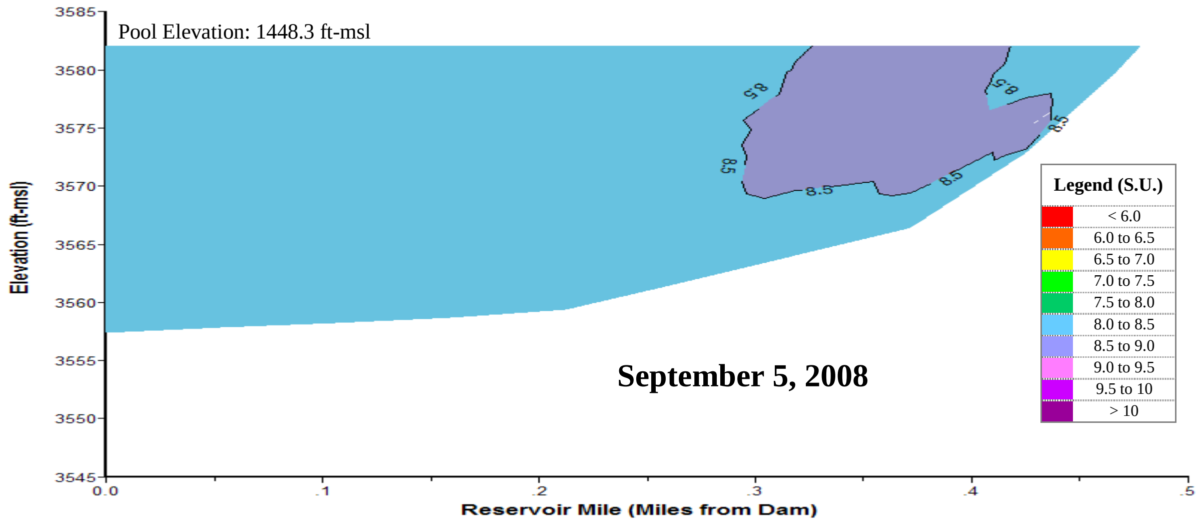


Plate 295. (Continued).

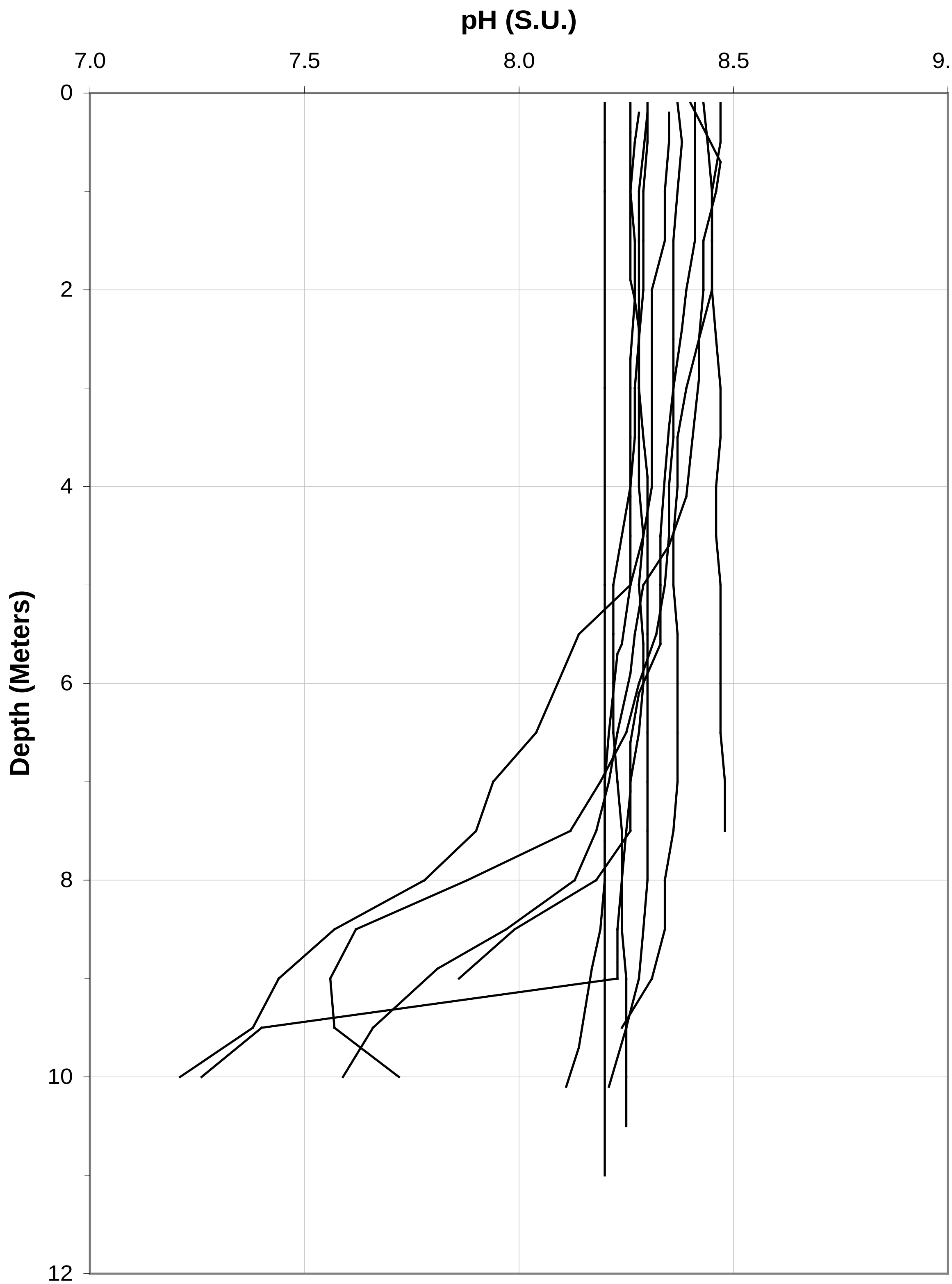


Plate 296. pH depth profiles for Cold Brook Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., CODLKND1) during the summer over the 10-year period of 2001 through 2010.

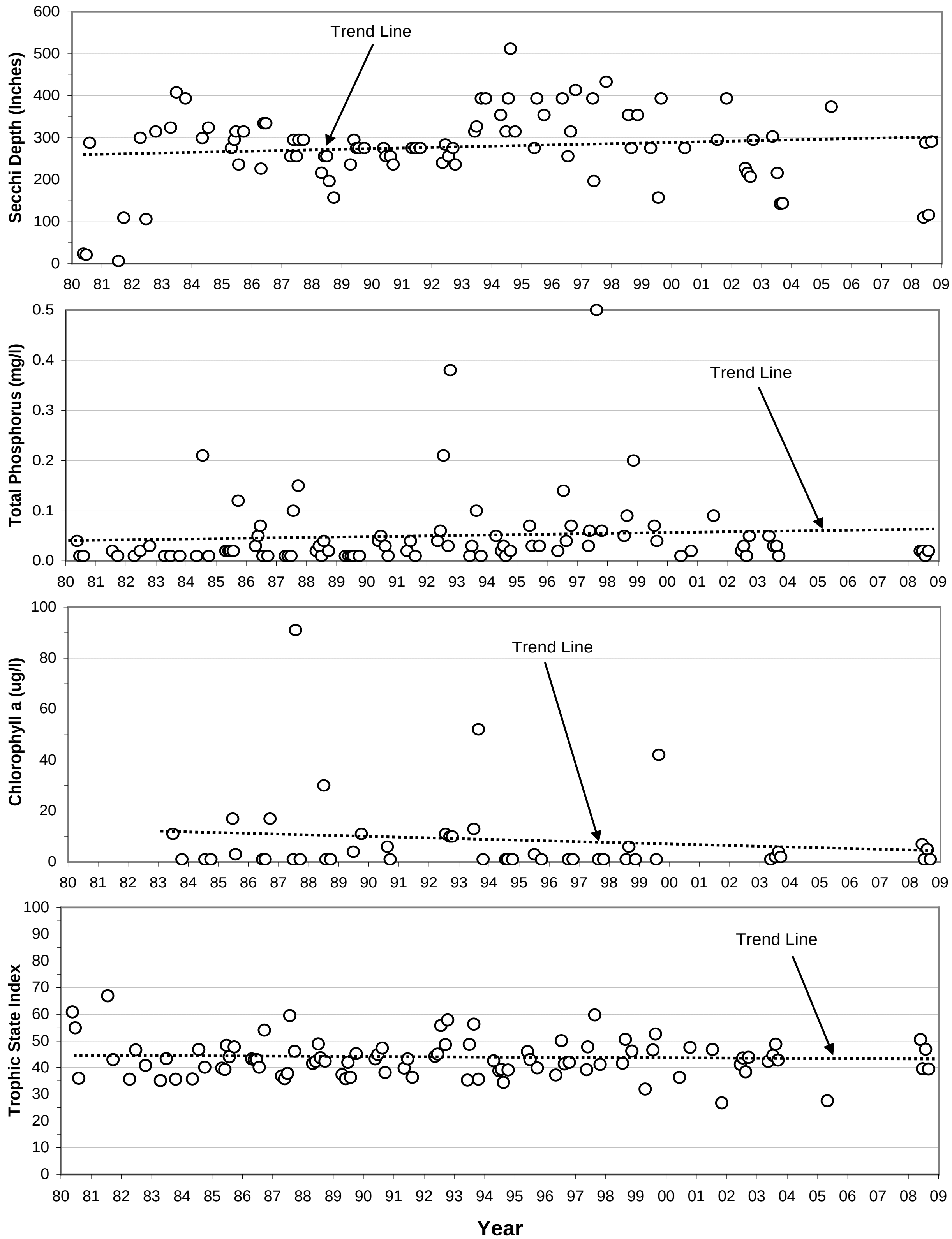


Plate 297. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Cold Brook Reservoir at the near-dam, ambient site (i.e., site CODLKND1) over the 31-year period of 1980 through 2010.

Plate 298. Summary of water quality conditions monitored in Cottonwood Springs Reservoir at the near-dam, deepwater ambient monitoring location (i.e., site COTLKND1) from May to September during the 2-year period 2001 and 2002. [Note: Results for water temperature, dissolved oxygen, conductivity, and pH are for water column profile measurements. Results for hardness, metals, and pesticides are for "grab samples" collected at ½ the measured Secchi depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	8	3867.1	3866.4	3863.8	3871.9	-----	-----	-----
Water Temperature (°C)	0.1	89	20.0	21.0	13.9	26.0	26.6	0	0%
Dissolved Oxygen (mg/l)	0.1	89	7.0	7.4	0.2	8.9	≥ 6, ≥ 5	13, 9	15%, 10%
Dissolved Oxygen (% Sat.)	0.1	89	87.4	89.5	2.0	118.6	-----	-----	-----
Specific Conductance (umho/cm)	1	89	1,685	1,750	905	1,829	-----	-----	-----
pH (S.U.)	0.1	87	8.0	8.0	7.4	8.3	≥6.5 & ≤9.0	0	0%
Secchi Depth (in.)	1	7	235	236	146	394	-----	-----	-----
Alkalinity, Total (mg/l)	7	12	89	86	51	158	-----	-----	-----
Ammonia, Total (mg/l)	0.2	4	-----	0.02	n.d.	0.60	8.41(1), 1.57(2)	0	0%
Hardness, Total (mg/l)	0.4	10	1,031	1,078	290	1,233	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	12	-----	0.1	n.d.	0.8	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	12	-----	n.d.	n.d.	0.09	10(4)	0	0%
Phosphorus, Total (mg/l)	0.02	12	0.02	0.02	n.d.	0.05	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	12	-----	n.d.	n.d.	n.d.	-----	-----	-----
Suspended Solids, Total (mg/l)	4	12	-----	n.d.	n.d.	6	158(1), 90(2)	0	0%
Antimony, Dissolved (ug/l)	6	1	-----	n.d.	n.d.	n.d.	6(4)	0	0%
Arsenic, Total (ug/l)	3	4	-----	n.d.	n.d.	5	340(1), 150(2), 0.018(3)	0, 0, b.d.	0%
Beryllium, Dissolved (ug/l)	0.5	1	-----	n.d.	n.d.	n.d.	4(3)	0	0%
Cadmium, Dissolved (ug/l)	0.5	1	-----	n.d.	n.d.	n.d.	50(1), 6(2)	0	0%
Chromium, Dissolved (ug/l)	2	1	-----	n.d.	n.d.	n.d.	3,936(1), 1,276(2)	0	0%
Copper, Total (ug/l)	2	4	-----	n.d.	n.d.	n.d.	164(1), 89(2), 1,300(3)	0	0%
Lead, Total (ug/l)	2	4	-----	n.d.	n.d.	n.d.	766(1), 30(2)	0	0%
Mercury, Dissolved (ug/l)	0.02	1	-----	n.d.	n.d.	n.d.	1.4(1)	0	0%
Mercury, Total (ug/l)	0.02	2	-----	n.d.	n.d.	n.d.	0.012(6)	b.d.	b.d.
Nickel, Dissolved (ug/l)	3	1	-----	n.d.	n.d.	n.d.	10,832(1), 1,203(2)	0	0%
Silver, Dissolved (ug/l)	1	1	-----	n.d.	n.d.	n.d.	216(1)	0	0%
Zinc, Total (ug/l)	3	4	-----	n.d.	n.d.	5	879(1), 802(2),7,400(3)	0	0%
Alachlor, Total (ug/l)(C)	0.05	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Atrazine, Total (ug/l)(C)	0.05	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Metolachlor, Total (ug/l)(C)	0.05	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Pesticide Scan (ug/l)(D)	0.05	1	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected. b.d. = Below detection.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) Acute criterion for aquatic life.
(2) Chronic criterion for aquatic life.
(3) Human health criterion for surface waters.
(4) Daily maximum criterion for domestic water supply.
Note: North Dakota's WQS criteria for metals are based on total recoverable, most analyzed metal concentrations were dissolved. Listed criteria are given for comparison and were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, atrazine, benfluralin, butylate, chlorpyrifos, cyanazine, cycloate, EPTC, hexazinone, isopropalin, metribuzin, metolachlor, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, profluralin, prometon, propachlor, propazine, simazine, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

Plate 299. Summary of water quality conditions monitored in Cottonwood Springs Reservoir at the mid-lake, deepwater ambient monitoring location (i.e., site COTLKML1) from May to September during 2002 and 2003. [Note: Results for water temperature, dissolved oxygen, conductivity, and pH are for water column profile measurements. Results for hardness, metals, and pesticides are for "grab samples" collected at ½ the measured Secchi depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	5	3864.1	3864.2	3862.1	3865.6	-----	-----	-----
Water Temperature (°C)	0.1	78	21.1	21.2	14.6	25.6	26.6	0	0%
Dissolved Oxygen (mg/l)	0.1	78	7.2	7.3	1.6	9.1	≥ 6, ≥ 5	9, 9	12%, 12%
Dissolved Oxygen (% Sat.)	0.1	78	91.5	92.7	19.3	117.9	-----	-----	-----
Specific Conductance (umho/cm)	1	78	1,775	1,782	1,706	1,827	-----	-----	-----
pH (S.U.)	0.1	78	8.1	8.0	7.4	8.9	≥6.5& ≤9.0	0	0%
Secchi Depth (in.)	1	5	233	221	202	276	-----	-----	-----
Alkalinity, Total (mg/l)	7	2	51	51	46	56	-----	-----	-----
Ammonia, Total (mg/l)	0.2	2	-----	n.d.	n.d.	n.d.	8.41(1), 1.55(2)	0	0%
Kjeldahl N, Total (mg/l)	0.1	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	2	-----	n.d.	n.d.	n.d.	10(4)	0	0%
Phosphorus, Total (mg/l)	0.02	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.02	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Suspended Solids, Total (mg/l)	4	2	-----	n.d.	n.d.	6	158(1), 90(2)	0	0%
Chlorophyll *a* (ug/l)	1	1	-----	n.d.	n.d.	n.d.	6(4)	0	0%
Alachlor, Total (ug/l)(C)	0.05	1	-----	n.d.	n.d.	n.d.	-----	-----	-----
Atrazine, Total (ug/l)(C)	0.05	1	-----	n.d.	n.d.	n.d.	-----	-----	-----
Metolachlor, Total (ug/l)(C)	0.05	1	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) Acute criterion for aquatic life.
(2) Chronic criterion for aquatic life.
(3) Human health criterion for surface waters.
(4) Daily maximum criterion for domestic water supply.
Note: North Dakota's WQS criteria for metals are based on total recoverable, most analyzed metal concentrations were dissolved. Listed criteria are given for comparison and were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, atrazine, benfluralin, butylate, chlorpyrifos, cyanazine, cycloate, EPTC, hexazinone, isopropalin, metribuzin, metolachlor, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, profluralin, prometon, propachlor, propazine, simazine, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

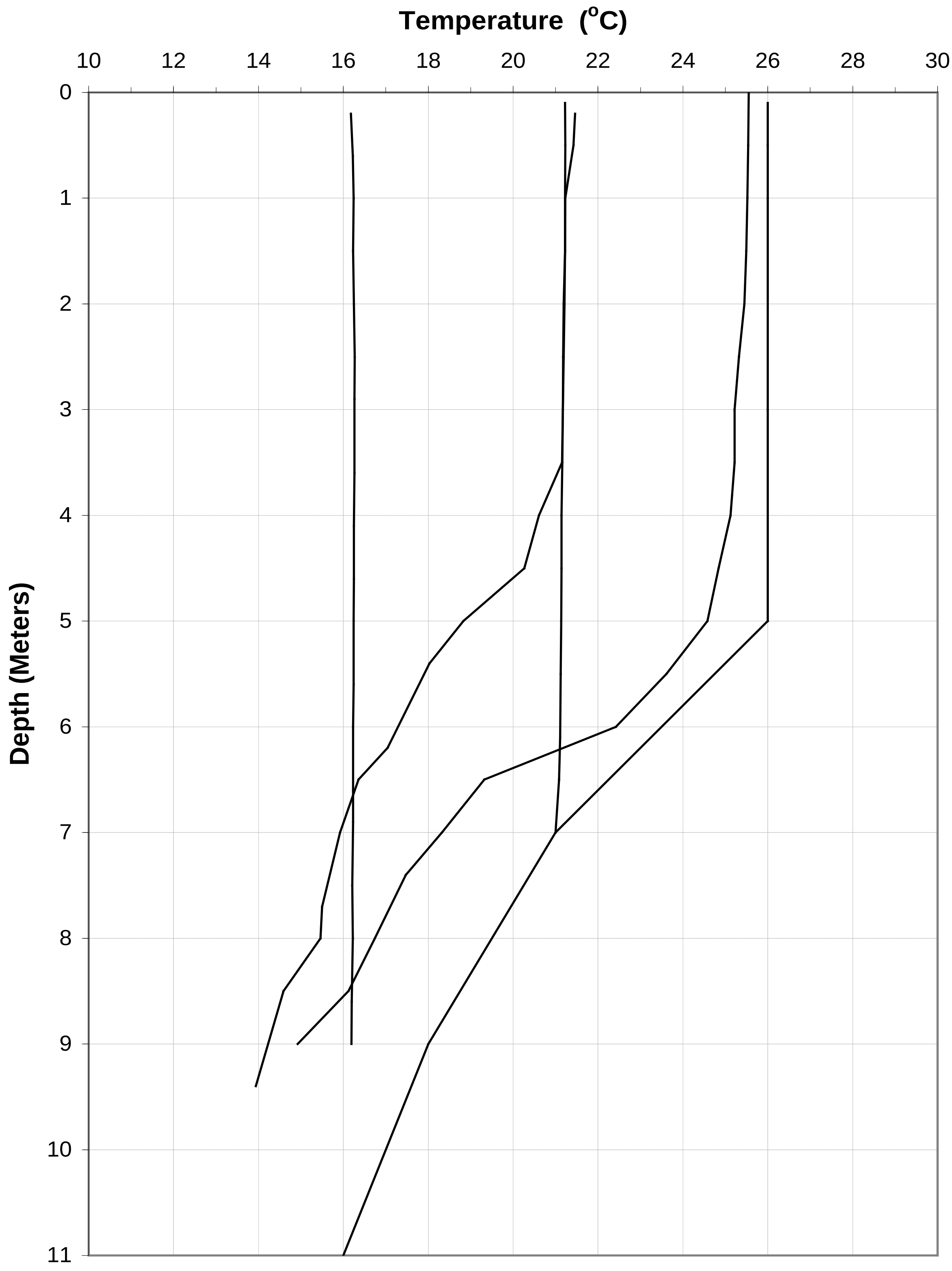


Plate 300. Temperature depth profiles for Cottonwood Springs Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., COTLKND1) during the summer of 2001 and 2002.

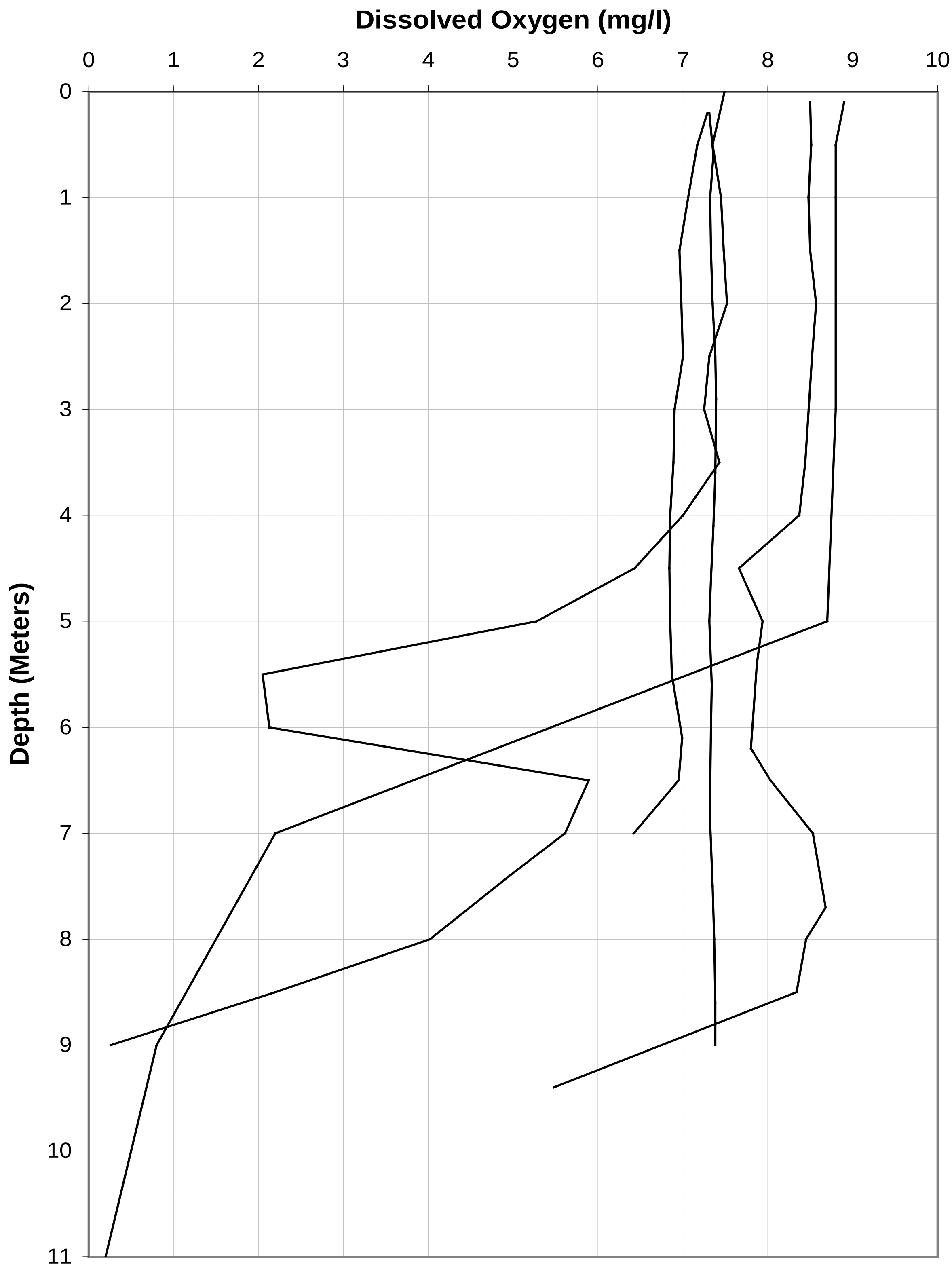


Plate 301. Dissolved oxygen depth profiles for Cottonwood Springs Reservoir compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., COTLKND1) during the summer of 2001 and 2002.